Task 4

Evaporation Ponds

Final Report

February 1999

Evaporation Ponds Technical Committee

The San Joaquin Valley Drainage Implementation Program

and

The University of California Salinity/Drainage Program

DISCLAIMER

This report presents the results of a study conducted by an independent Technical Committee for the Federal-State Interagency San Joaquin Valley Drainage Implementation Program. The Technical Committee was formed by the University of California Salinity/Drainage Program. The purpose of the report is to provide the Drainage Program agencies with information for consideration in updating alternatives for agricultural drainage water management. Publication of any findings or recommendations in this report should not be construed as representing the concurrence of the Program agencies. Also, mention of trade names or commercial products does not constitute agency endorsement or recommendation.

The San Joaquin Valley Drainage Implementation Program was established in 1991 as a cooperative effort of the United States Bureau of Reclamation, United States Fish and Wildlife Service, United States Geological Survey, United States Department of Agriculture-Natural Resources Conservation Service, California Water Resources Control Board, California Department of Fish and Game, California Department of Food and Agriculture, and the California Department of Water Resources.

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FINAL REPORT

EVAPORATION PONDS

by

Technical Committee on Evaporation Ponds

for

San Joaquin Valley Drainage Implementation Program

February 2, 1999

Preface and Acknowledgements

The Technical Committee on Evaporation Ponds prepared this report, one of eight reports commissioned by the San Joaquin Valley Drainage Implementation Program. Each of the Technical Committees (source reduction, drainwater reuse, drainwater treatment, land retirement, evaporation ponds, groundwater management, river discharge, and salt utilization) were charged to produce a comprehensive scientific and economic evaluation on management issues dealing with the drainage and salinity issues in the westside of the San Joaquin Valley. The Technical Reports will review the work done on drainage problems since the recommendations of the 1990 "Management Plan for Agricultural Subsurface Drainage and Related Problems of the Westside San Joaquin Valley". The Technical Reports will also expand on the status appraisal made in the 1998 "Status Report on Drainage Management in the San Joaquin Valley".

In its initial meeting, this Technical Committee generated the following burning questions:

1. Can evaporation basins be eliminated in irrigated lands with no surface discharge outlets?

2. Do evaporation ponds affect total bird population in the valley (net decrease or net increase or minimal)?

3. What drainage water characteristics make evaporation ponds bird safe (are all ponds potentially toxic)?

4. How can evaporation basins be managed to minimize (reduce) bird damage?

5. Can alternative and compensation habitats mitigate damages from ponds and can they be quantified?

6. Do we know the relationship between pond Se concentration and bird toxicity with sufficient certainty?

7. When ponds are deactivated, what are the appropriate closure procedures?

8. Are there any new promising technologies/studies that should be investigated?

9. Are the holding ponds and re-circulation basins present in the Westlands and Grassland subareas that look like evaporation ponds, but not operated as such, of concern?

10. Is the 1990 recommended mitigation ratio of one acre of compensation habitat for one acre of contaminated (>2 ppb Se) of pond surface appropriate?

11. What are the costs of design, construction and operation of evaporation ponds and alternative habitats?

These and other questions are addressed herein by the Technical Committee on Evaporation Ponds. The committee held a series of meetings for about a year to develop an outline and prepare writeups. The writeups for each section in this report were typically written by one individual and then reviewed and edited by either a subcommittee or the entire committee. The chair is very appreciative for the initial writeups by individuals.

Manucher Alemi, the SJVDIP Coordinator, participated in all our meetings and provided valuable guidance and encouragement. John Letey, Activity Manager from the University of California, provided overviews and served as an ex-officio member. This committee acknowledges the able assistance of Wayne Verrill, Department of Water Resources, who took copious notes and assisted in the distribution of minutes and working draft reports.

The Technical Committee on Evaporation Ponds consisted of the following:

Active Committee Members:

Christopher Amrhein	University of California, Riverside
Douglas Barnum	U.S. Fish and Wildlife Service, Delano
Douglas Davis	Tulare Lake Drainage District, Corcoran
Jack Erickson	Department of Water Resources, Fresno
Charles Hanson	Hanson and Associates, Walnut Creek
Richard Higashi	University of California, Davis and Bodega Bay
Dale Mitchell	Department of Fish and Game, Fresno
Phillip Nixon	Lost Hills Water District, Bakersfield
Walter Shannon	State Water Resources Control Board, Sacramento
John Shelton	Department of Water Resources, Fresno
Jeffrey Single	Department of Fish and Game, Fresno
Jack Stone	Stone Ranches, Five Points
Anthony Toto	Central Valley Regional Water Quality Control Board, Fresno
Arthur Unger	Sierra Club, Bakersfield
Lonnie Wass	Central Valley Regional Water Quality Control Board, Fresno
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John Letey	University of California, Riverside
Wayne Verrill	Department of Water Resources

Table of Contents

Executive Summary

Agricultural evaporation basins are utilized for the disposal of saline drainwater where there are no opportunities for discharge into the San Joaquin River. Between 1972 and 1985, 28 evaporation ponds were constructed covering a surface area of about 7,100 acres, mainly in the environs of the Tulare Lake Basin. Presently only 10 ponds with a surface area of about 4,900 acres are active and managed by seven operators. The remainder has been voluntarily deactivated due to the high costs of meeting the waste discharge requirements and mitigation measures or closed by order of the SWRCB/CVRWQCB due to toxic effects of selenium to waterbirds from selenium present in the impounded waters.

A variety of waterfowl and shorebirds seasonally inhabit or utilize evaporation basins for resting, foraging and nesting. Waterbirds may be impacted adversely from exposure and bioaccumulation of selenium in their food chain. These adverse impacts may range from impaired health and condition of adult waterbirds, reduced hatchability of eggs and embryonic deformity. Although species–specific differences exist among the waterbirds, the focus has been mainly on American avocet and black-necked stilt. A number of complex interacting environmental and biological factors need to be taken into account to assess the potential adverse effects of selenium to wildlife.

The selenium concentrations in subsurface drains discharged to evaporation ponds vary widely, ranging from less than 2 to more than 200 ppb. Waterborne and sediment selenium readily bioaccumulates into the aquatic food chain by bioconcentration and biomagnification mechanisms. The extent of bioaccumulation depends on the route of exposure (e.g., diet, water or sediment) and chemical form of selenium. Research has been conducted on selenium speciation in waters and sediments and their uptake by plants such as widgeongrass, macroinvertebrates such as brine fly, and vertebrates such as Mosquitofish. The pathways and fate of selenium in the aquatic foodchain and toxicity to higher trophic forms are complex. There is a need to consider not only water borne selenium but also sediment selenium in assessing potential hazards to wildlife. It is currently thought by some that protein selenium in the food chain is more toxic than other forms of selenium.

Presently available scientific-based risk analyses indicate that such analyses require site- and species-specific appraisals, including spatial and temporal variabilities. Although selenium is the principal constituent of concern, others such as salts and boron are of concern, too. A number of other uncertainties exist in evaluating potential biological risks of selenium in ponds including, but not limited, to post-hatch juvenile mortality, the form of selenium in the pond system, sub-lethal exposure effects, and short-term exposure on migratory birds.

Other factors such as predation, flooding of nests, entrapment in tires used to stabilize banks and phosphate foams along shorelines, diseases such as avian botulism, and levee maintenance and other disturbances must be evaluated as separate risk analysis and risk management.

Investigations on treatment technologies to reduce the concentration level of selenium before discharge into streams and ponds were a major effort by the SJVDP. The methods can be broadly categorized into desalination, anaerobic microbial cultures, phytoremediation using flow-through microalgae cells and vegetated wetlands, and chemical reduction of selenium by metallic iron and iron compounds. All of these methods have had limited successes but costs and/or removal effectiveness have been major limitations. These treatment systems do not appear to remove selenium to sufficiently low concentration levels, about 2 ppb, so as not to impact wildlife.

Presently, the algal-bacterial flow-through system at Panoche Water District and the flow-through wetland system at Tulare Lake Drainage District are under investigation. In the latter system the removal of selenium from the inflow water before discharge into evaporation basins is through algal and plant volatilization of selenium, microbial and chemical reduction to elemental form, adsorption of selenite on reactive mineral and organic surfaces, and plant uptake. An inadvertent loss mechanism is seepage in the flow-through cells. The range of selenium removal concentration-wise varies with wetland plant species from about 18 % to 70 % of the 13.5 ppb influent selenium. There is, however, a potential wildlife hazard of the selenium accumulating in the wetland cells.

Another approach being studied is the sequential reuse of saline drainwaters on increasingly salt and boron tolerant crops, trees, grasses and halophytes at the Mendota site, Red Rock Ranch, Tulare Lake Drainage District, and Westlake Farms, Inc.. Reuse of drainwater as well as root water extraction from shallow ground water reduces the volume that needs to be further managed. At both the Red Rock Ranch and Mendota site, the hypersaline residual drainage waters produced from reuse are disposed into solar evaporators. The solar evaporator differs from evaporation basins in that the inflow to the evaporator is regulated to be less than or equal to real-time evaporation rates. The solar evaporator, if properly operated, should minimize hazards to wildlife and facilitate salt harvesting.

At the Rainbow Ranch evaporation basin, shorebird eggs collected in the 1994-96 season had lower than expected Se levels, 12 vs. 38 ppm mean dry weight. Apparently, this was the result of change in operation of the pond facility to one in which maximum salinity levels are kept as low as possible by re-routing fresh drainwater to those of higher salinity. The Department of Water Resources (DWR) has entered into an agreement with Rainbow Ranch to ascertain the factor(s) that caused a lower than expected selenium levels in shorebird body tissues and eggs.

Most recently, Tulare Lake Drainage District, Lost Hills Water District and Westlake Farms, Inc. are contracting with Novalek, Inc., for the commercial harvesting of Artemia brine shrimp from their hypersaline evaporation basin. The harvested brine shrimp, containing about 0.5 to 1.2 ppm Se wet weight, is used for feed in aquariums and aquaculture. Harvesting of brine shrimp will reduce selenium-containing food for waterbirds and the selenium load in the basins as well as provide some income to the pond operator.

Prior to 1985, evaporation basins were regulated by waste discharge requirements (WDRs) or by waiver of WDRs. But the Central Valley Regional Water Quality Control Board (CVRWQCB) stopped issuing waivers after Kesterson Reservoir was closed. In 1989, studies conducted by the U.S. Fish and Wildlife Service (USFWS) revealed impacts to wildlife in Tulare Lake Basin evaporation basins similar to those found at Kesterson Reservoir. In 1989, after the CVRWQCB circulated the tentative WDRs, the California Department of Fish and Game (DFG) commented that cumulative impacts to wildlife must be addressed. As an interim measure to protect wildlife, pond operators and DFG entered into Memorandums of Understanding (MOU) regarding basin management. Actions contained in the MOUs to reduce impacts to wildlife included minimum water depth of 2 feet, levee slopes as steep as practicable, vegetation control, removal of windbreaks, disease surveillance and control program, invertebrate sampling, and bird hazing. In 1993 the cumulative environmental impact report (EIR) and 14 site-specific EIRs were certified by the CVRWQCB and WDRs were issued.

The EIRs and WDRs were appealed by the USFWS, environmental organizations, and two members of the public. Specific mitigation measures incorporated into the 1993 WDRs were implemented by basin operators. In 1995, the USFWS developed mitigation habitat protocols based in large part to data generated from the implemented mitigation measures. The State Water Resources Control Board (SWRCB) remanded the EIRs and WDRs for three of the active evaporation basins while the rest were settled or closed. As part of "settled" WDRs, basin operators are required to submit three year assessment reports to evaluate the effectiveness of the mitigation measures implemented such as compensation and alternative habitats. DWR, USFWS and DFG will review these reports. The CVRWQCB entered into MOUs with three operators to select a consultant to prepare EIRs to address relevant CEQA issues as directed by SWRCB, and this process is ongoing.

Those basins shut down are subject to closure and post-closure maintenance plans. As a first step in closing evaporation basins, all free liquids are removed. Then closure may proceed in one of two ways: "clean-close" or "close-in-place". In "clean-close", all residual wastes are completely removed and discharged to an appropriate waste management unit. In "close-in-place", all residual wastes are compacted and the basin closed as a landfill as described in California Code Title 27, Regulations for the Treatment, Storage, Processing or Disposal of Solid Waste. The Code requires that a cap of at least a foot in thickness be placed over the waste with a permeability of $1x10^{-6}$ cm/sec or less to minimize water infiltration. In addition, a soil cover of at least a foot must be placed on top of the cap with a vegetative cover to prevent erosion and maintain the integrity of the cap. The final soil cover must be graded to prevent surface ponding. The bottom of the compacted waste must be at least 5 feet from the ground water. Post closure plans require an annual inspection to observe the integrity of cover and place additional soils as needed and maintain vegetative cover. These closure and post-closure requirements are intended to prevent windblown basin sediments from being transported off site, limiting access of waterfowl and shorebirds to the basin sediments, and preventing any substantial impacts to ground water quality.

The results of site-specific environmental analyses showed that some evaporation basins, such as those operated by Stone Land Company and Meyer Farms, are characterized by low waterborne selenium concentrations and the risk of potential adverse effects on waterbirds is minimal so that compensation for unavoidable losses are not necessary. At other basin facilities, such as those operated by Tulare Lake Drainage District, Westlake Farms, Britz, Lost Hills Water District and Rainbow Ranch, modifications to evaporation basins and/or compensation for unavoidable losses has been identified. A number of protocols have been proposed to estimate unavoidable adverse impacts on American avocet and black-necked stilts, and the acreage of uncontaminated compensation wetland to mitigate these unavoidable losses.

Moreover, a second protocol has been proposed for the creation of alternative wetland habitats to provide foraging habitats for targeted waterbirds so that selenium dosing from contaminated basins could be reduced. Based upon preliminary estimates of unavoidable losses and required compensation and/or alternative habitats, WDRs were adopted for evaporation basins operated by Westlake Farms, Tulare Lake Drainage District's South and Hacienda Evaporation Basins, Lost Hills Water District and Rainbow Ranch.

These protocols to calculate compensation-alternative habitats utilize site-specific information on waterborne selenium concentrations, abundance of nesting stilts and avocets at the evaporation basin, and the anticipated density (number per acre) of stilts and avocets at a managed wetland site. The site-specific approach to evaluating compensation habitat has resulted in requirements for some evaporation basins, such as the Tulare Lake Drainage District's South and Hacienda Evaporation Basins, Westlake Farms, Inc., Stone Land Company and Meyer Farms, in compensation requirements substantially less than the 1:1 evaporation basin: compensation habitat suggested in the 1990 San Joaquin Valley Drainage Report.

Results of biological monitoring conducted since 1993 have shown substantial reductions in the numbers of waterbirds, particularly American avocet and black-necked stilts, nesting at evaporation basins after modifications have been implemented and that the numbers of stilts and avocets successfully nesting at compensation habitats is substantially higher than originally expected. Investigations are continuing to provide additional information regarding the potential benefits associated with alternative wetland habitat, the use of low-selenium saline water supplies for wetland habitat, and other scientific investigations and monitoring activities. Monitoring of waterbird nesting, abundance, nest fate, egg selenium, and embryonic conditions within operating evaporation basins and compensation and/or alternative habitat will continue in compliance with requirements of the WDR's.

Information developed since 1993 regarding compensation habitat show that: (I) compensation wetland habitat can be designed and operated successfully to support high densities of nesting waterbirds; (ii) nesting success has been shown to be high at several compensation habitats where predator exclusion has been effective; (iii) a carefully designed vegetation control program can contribute to the long-term success of the mitigation site;

(iv) relatively large numbers of young waterbirds are produced at compensation wetland habitats when compared to current estimates of waterbird nesting at several of the evaporation basins managed in accordance with the WDR's, however, the contribution of production from these areas to the adult population and the net environmental benefits of compensation habitats have not been quantified; (v) various protocols used to estimate compensation habitat requirements have been refined using biological data collected since 1993 and produce very similar estimates of habitat requirements based on site-specific information regarding evaporation basin characteristics; and (vi) a scientific site-specific calculation of compensation habitat requirements has been developed and is being tested in the Tulare Lake Basin. This site-specific approach resulted in lower estimates of compensation habitat requirement compared to the 1:1 pond: habitat ratio recommended in the 1990 plan.

The results of biological monitoring at mitigation wetland habitats conducted to date have been promising. Monitoring is continuing to refine the performance of compensation habitats and to address questions concerning issues such as the use of saline water supplies having low-selenium concentrations as a water supply to wetlands, performance under drought conditions, alternative wetland design and operations, and the relationship between waterbird production on compensation wetlands relative to the mitigation requirements to reduce unavoidable evaporation basin impacts to less-than-significant levels, the function of alternative habitats for reducing selenium dietary loads, and the contribution of compensation habitat production to the adult waterbird population and the associated assessment of net environmental benefits.

In summary, evaporation basins along with other alternative drainage management options play a major role in sustaining agriculture in drainage impacted lands, particularly the Tulare/Kern sub-area. However, the presence of naturally occurring selenium in the impounded drainage waters is of concern to wildlife, especially waterbirds. From 1989 to the present, adverse selenium impacts to American avocet and black-necked stilts have been studied extensively in the environs of Tulare Lake Basin. Modifications in the design and management of evaporation basins have been implemented. For those basins with impacts on waterbirds, site-specific mitigation measures have been adopted such as compensation and alternative habitats. The results of biological monitoring of such mitigation measures show considerable promise of protecting waterbirds. There is a need to obtain more quantitative data to establish the effectiveness of mitigation measures as well as manage and utilize the deposited salts in evaporation basins.

I. Introduction and Overview on Evaporation Ponds

IA. Why are evaporation ponds needed?

Water disposal basins in natural depressions have been utilized for centuries by agriculture to impound irrigation runoff waters and dissipate them by evaporation, seepage and evapotranspiration losses (Tanji et al., 1993). However, basins constructed and managed for the evaporation of saline irrigation drainage waters are a comparatively new practice.

In the San Joaquin Valley westside, agricultural evaporation ponds are constructed in drainage-impacted areas where there are no opportunities for drainage discharge into the San Joaquin River. Figure IA-1 shows the location map of 28 evaporation basins constructed between 1972 and 1985 covering a surface area of about 7,100 ac (Ford, 1988). Moore et. al. (1990) reported a total of 7,400 ac based on aerial photographs that were digitized and included overflow areas that were utilized by birds intermittently. Of the 28 ponds, 10 are still active (about 4,900 ac) and managed by seven operators while the remainder has been deactivated voluntarily or by closure orders. Note that the majority of the ponds are located in the Tulare and Kern Sub-basins, the southern one thirds of the San Joaquin Valley. The Tulare/Kern Subarea is a hydrologically closed basin, except when extreme flood events form a high stage Tulare Lake and spills over into the San Joaquin River.

Hydrogeologic investigations by Croft (1972) indicated that the ground water bearing deposits in the Tulare/Kern Subarea contain six clay tongues (A through F). The E-Clay (Corcoron Clay member) is the most prominent with a thickness between 60 and 75 ft at about 800 ft below the land surface of Tulare Lake bed. The A-Clay lies at 10-60 ft having a thickness of about 60 feet and the C-Clay occurs at a depth of 220-300 ft having a thickness of about 10 feet beneath the Tulare Lake bed. The B-, D- and F-clay layers are of limited extent. The E-Clay is the principal confining layer and the A-Clay appears to impede downward deep percolation of irrigation drainage.

The presence of these nearly water-impermeable clay layers in the subsurface and use of imported surface water supplies for irrigation have contributed to high water table. Belitz (1988) believes that perched water tables do not exist in the westside of the valley, and instead the vadose has been filled up with irrigation drainage. Deep percolation of applied irrigation water occurs because irrigation application systems are not 100% efficient, spatial variabilities exist in soil hydraulic properties, pre-irrigation is practiced in the fall and winter, and extra water is applied for seed germination and leaching salts from the crop root zone.

Figure IA-2 is a 1997 map (DWR, 1997) of the drainage problem area in the Tulare/Kern sub-basins. The total area occupied by water table at 0-5 ft below the land surface is 359,000 ac. Croplands having a water table 0-5 ft should be drained to sustain

Figure IA-1. Evap Pond Location Map

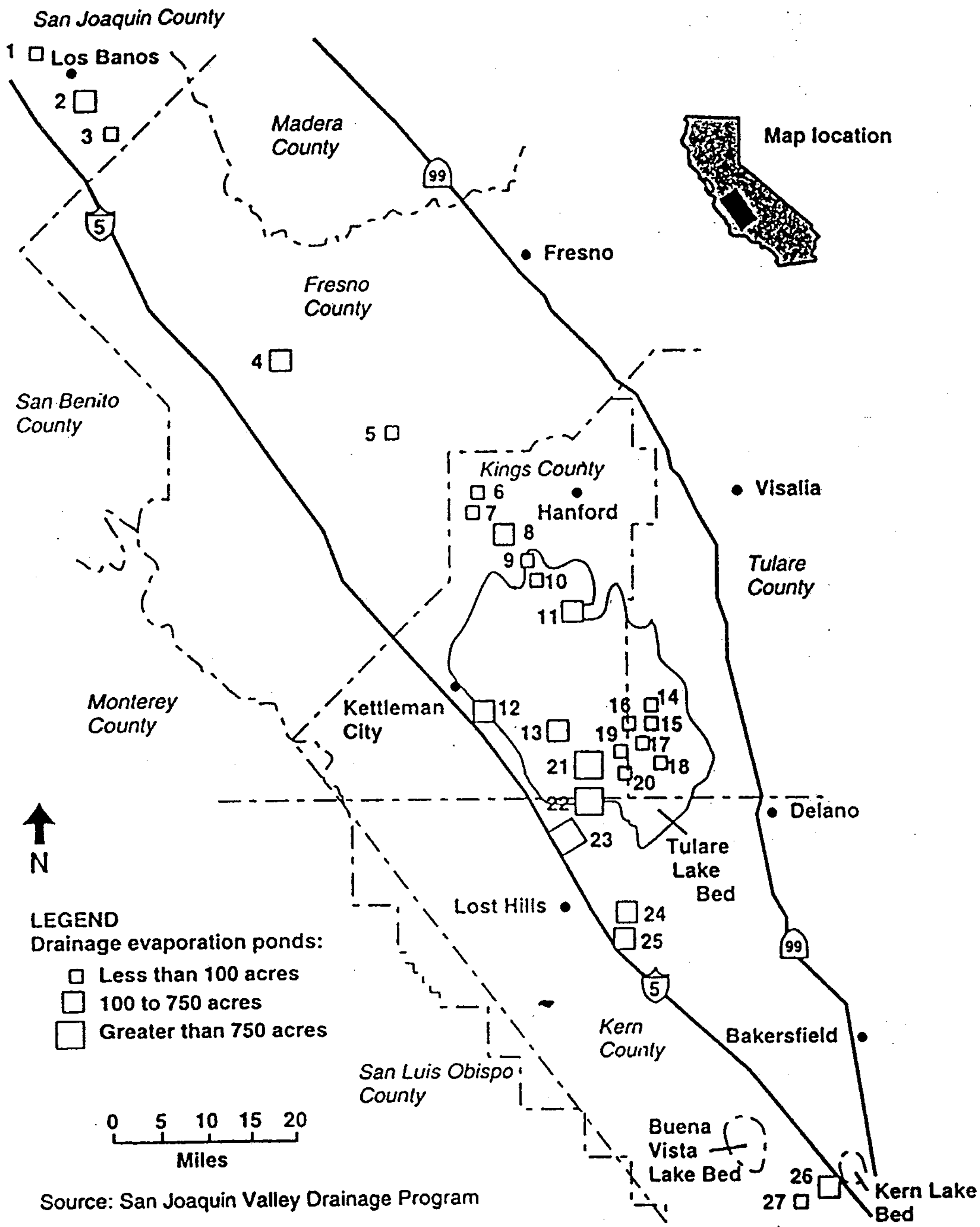
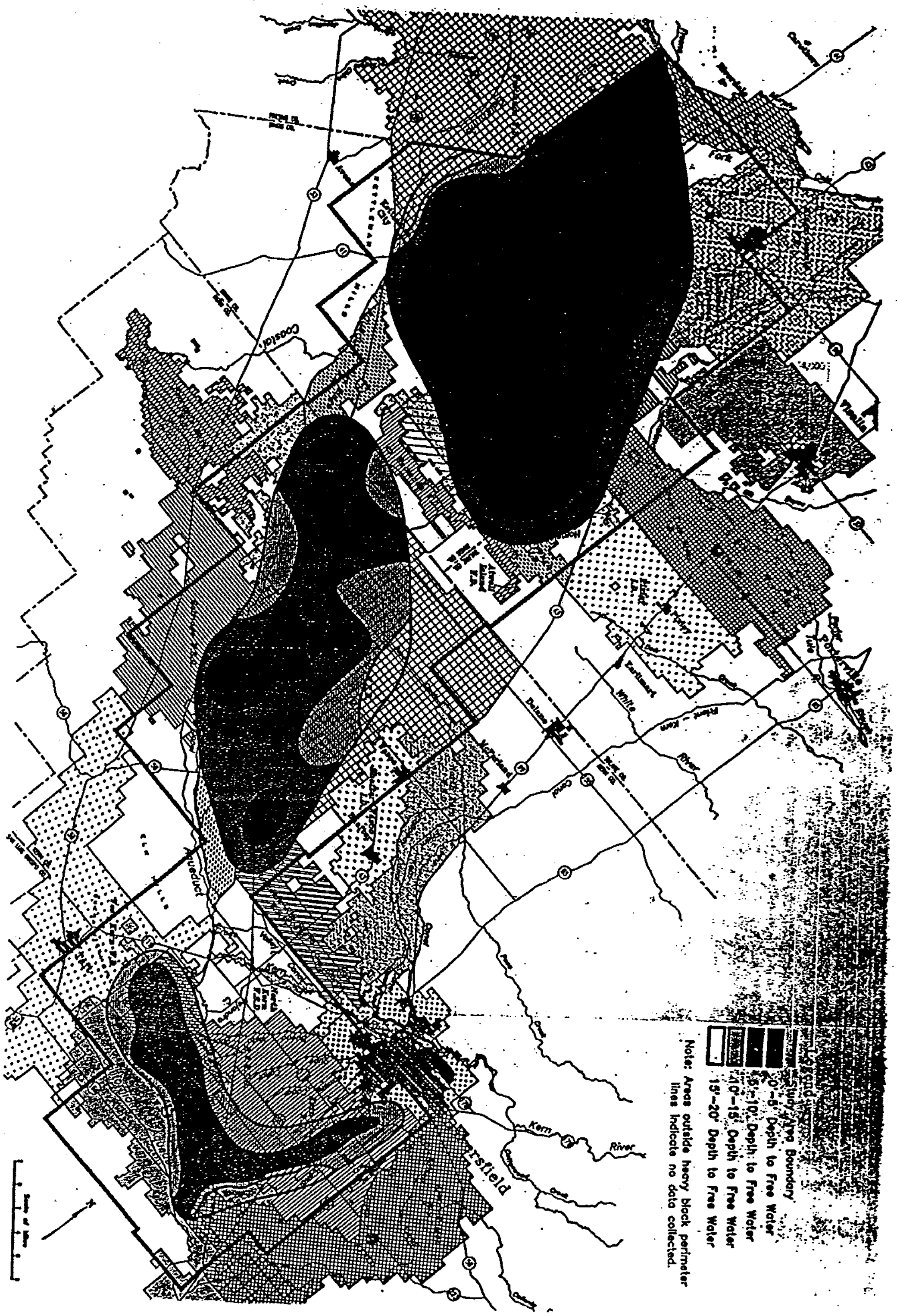


Figure IA-2. Drainage Problem area map in Tulare/Kern Subarea, 1997 (DWR)



agricultural productivity. But since the Tulare/Kern area does not have any drainage outlet to the San Joaquin River, the collected subsurface drainage waters are disposed into evaporation basins. Other options for managing saline drainage waters include reuse as irrigation of salt tolerant trees, crops, grasses and halophytes as well as in-situ rootwater extraction by deeper rooted crops. The Technical Committee on Drainwater Reuse discusses these reuse options. To date, evaporation ponds are the only economic means of disposal of moderately saline waters south of the San Joaquin River system.

IB. In-Valley vs. Out-of-Valley Management Options

In-valley management options have been described in detail in the San Joaquin Valley Drainage Program (SJVDP) Final Report (SJVDP, 1990). The SJVDP recognized that the recommendations in the 1990 Report did not represent a “single, sure, and lasting solution to the drainage problem”. Rather, they were a means to manage the drainage problem over a period of decades and were a necessary first step in developing a more permanent solution. The SJVDP did not consider out-of-valley options; however, it was recognized that “ultimately, it may become necessary to remove salt from the valley.”

Out-of-valley options generally involve some sort of “master drain” for export of salts. They differ only in the type of conveyance considered, the location of the discharge, and the required pretreatment (contaminant reduction, volume reduction). The need for drainage facilities was recognized in the earliest planning stages of the San Luis Unit of the Central Valley Project and the State Water Project (Letey et al., 1986).

The export of salts in crystallized form is not considered an out-of-valley option in this report since the quantities required to have a meaningful impact on the salt balance in the valley cannot (presently) be feasibly disposed of, and suitable markets or beneficial uses have not been identified. Export of smaller quantities from individual farms using solar ponds etc. may be feasible however. This option is discussed in the report by the Salt Utilization Technical Committee.

Historical Background

In 1960, Congress enacted Public Law 86-488 authorizing construction of the San Luis Unit of the Central Valley Project. This law required the U.S. Bureau of Reclamation (Bureau) to either participate with the State in constructing a "master drainage outlet and disposal channel for the San Joaquin Valley" or to construct the "San Luis Interceptor Drain to the Delta designed to meet the drainage requirements of the San Luis Unit" (SJVIDP, 1979).

In 1964 the California Department of Water Resources (DWR) and the Bureau began planning for a San Joaquin master drain. The master drain would extend from Buena Vista lakebed in the southern valley to a discharge point near Antioch and would obviate the need for a separate drain for the San Luis Unit. After nearly three years of planning, DWR withdrew from the project due to funding limitations and the Bureau proceeded with construction of the San Luis Interceptor Drain (SJVDIP, 1998).

The Bureau began construction of the San Luis Drain (the term "interceptor" was dropped from the name) in 1968 and completed an 82-mile segment between Kesterson Reservoir near Gustine and southern Fresno County. Approximately 7,000 ac-ft. per year were discharged to this facility until problems with wildlife at Kesterson Reservoir were observed in 1983 and traced to selenium. This led to the issuance of a Cleanup and Abatement Order for Kesterson Reservoir and the eventual closure of both the San Luis Drain and Kesterson Reservoir.

Between 1975 and 1979 the San Joaquin Valley Interagency Drainage Program (IDP) conducted a comprehensive analysis of the drainage problem. The IDP was a joint effort by the Bureau, DWR and the State Water Resources Control Board (SWRCB) to formulate a plan for agricultural drainage and salt management in the San Joaquin Valley. The IDP published a Final Report and first-stage Environmental Impact Report in 1979 containing a recommended plan for agricultural drainage. This plan called for a valley-wide drain to be completed in phases between the Kern Lakebed in the south and Suisun Bay near Chipps Island.

The Bureau began the application process for a discharge permit for the San Luis Drain in the early 1980’s but abandoned its efforts when Kesterson Reservoir was closed. As a result of a recent lawsuit brought before the U.S. District Court by various plaintiffs against the Bureau for failure to provide drainage service to the San Luis Unit, the Court ordered the Bureau to seek a discharge permit for the San Luis Drain. The Bureau initiated discussions on a discharge permit with the SWRCB in 1995, but little progress has been made, nor is expected pending the outcome of an appeal of the Court’s decision.

Lack of a drainage outlet has left few options for farmers in the southern San Joaquin Valley. As indicated in Section I.A in this Report, evaporation ponds have been constructed in areas where hydrologic conditions do not permit the discharge of drainage water to natural or manmade waterbodies. Thus, the greatest concentration of evaporation ponds is found in the hydrologically-closed Kern/Tulare Subarea (Figure IA-1).

Advantages and Disadvantages

There are advantages and disadvantages to in-valley and out-of-valley management options. It is likely that the most suitable alternative for the long term is not one or the other but some combination of in-valley and out-of-valley management options. The options are not mutually independent, and implementation of an out-of-valley option would involve the integration of a number of in-valley drainage management systems.

The following is a listing of what are felt to be the most significant advantages and limitations of each option. The suitability and feasibility of either one cannot be determined by a simple comparison of those listed here because the environmental, economic, social and political significance of each factor varies widely.

The advantages, or actions leading, to managing drainage water and salts within the valley include:

1. Promotion of water conservation and improved water management.

2. Promotion of the use of shallow water tables for crop evapotranspiration.

3. Promotion of reuse of collected drainwater.

4. Full protection of environmentally sensitive areas such as the San Joaquin River and Bay-Delta.

5. A higher degree of public acceptance, especially outside the San Joaquin Valley.

Some may argue that items 1, 2, and 3 above should be happening regardless of in-valley or out-of-valley management.

The disadvantages of in-valley management include:

1. Accumulation of salt, selenium, and boron in the root zone.

2. Increase in the concentration of toxic constituents through evaporation.

3. Increase in land degradation and loss of agricultural productivity.

4. Limits on the ability to produce salt-sensitive crops.

5. Increases in salt loading to the vadose zone and useable aquifers.

6. Lack of identified economic value to, or suitable markets for, the byproducts of drainage disposal.

7. Not all areas are suitable geologically for in-valley disposal.

The advantages of out-of-valley drainage disposal include:

1. Enables a basin-wide salt balance and maintenance of a favorable salt balance in the crop root zone.

2. Avoids the potential negative environmental impacts of in-valley disposal.

3. Enables the most land to stay in production.

4. Will likely have the lowest net economic cost in the long term.

The disadvantages of out-of-valley disposal include:

1. Potential negative impacts on receiving waters.

2. High initial cost.

3. Lack of public acceptance and political/institutional feasibility.

4. Planning and permitting requirements will be complex.

IC. An Overview of Evaporation Systems from 1990 to 1998

Evaporation ponds of the future envisioned by SJVDP bear little resemblance in structure or operation to ponds that existed in 1990. The SJVDP recommendations for evaporation ponds included the selection, design, and operation of ponds. The design and construction recommendations were based on DFG criteria, which called for steep interior levee slopes and minimum pond depth to minimize shore bird use. In addition, SJVDP recommended that if pond influent selenium concentration should exceed 2 ppb, alternative safe habitat equal to the evaporation pond area should be provided to facilitate waterfowl hazing. If the influent selenium concentration should exceed 50 ppb, accelerated-rate evaporation ponds would be used to reduce required pond areas because traditional ponds would not be feasible in the long run for such conditions.

The plan provides for constructing new evaporation ponds for 2000 and 2040 covering 2,600 and 7,600 acres, respectively. All ponds would be associated with agroforestry or other drainage reuse systems; some would be solar (lined with black plastic) and some would have accelerated rates of evaporation (e.g., through overhead sprinklers). The new, smaller evaporation ponds would serve a proportionately larger acreage of tile-drained farmland than existing ponds because agroforestry evapotranspiration systems would result in reduced drainage volume. A given acre of evaporation pond could serve eight to ten times more acreage of farmland than in 1990.

Evaporation ponds for the disposal of drainage water have been a major concern to CVRWQCB because of wildlife impacts. In August 1993, the CVRWQCB adopted Waste Discharge Requirements for the continued operation of evaporation ponds. Some pond operators reported that they would cease operation for a significant acreage of existing ponds. The surface area of ponds constructed by late 1980's was about 6,700 acres in Tulare and Kern subareas. The surface area of active evaporation ponds in 1995 for which CVRWQCB had prescribed Waste Discharge Requirements was 5,444 acres.

Waste Discharge Requirements define requirements and compliance schedules designed to discourage wildlife use of evaporation ponds and/or provide mitigation and compensation measures to offset the adverse effects of evaporation ponds. As a result, much has been done in the design, construction, and operation of ponds to discourage wildlife use. To reduce wildlife use of ponds, Waste Discharge Requirements require steepening of interior pond slopes and removal of levee windbreaks that had been constructed to reduce wave action and levee erosion. In addition to modifying pond construction, improved water distribution and water control structures are required to maintain deeper water levels that reduce bird -feeding habitat.

Table ID-1, an update of Table 5 in SJVDIP (1998), compares SJVDP and CVRWQCB recommendations for existing evaporation ponds. The CVRWQCB did not follow SJVDP's recommendations that required alternative habitat equal to evaporation pond area where influent selenium concentration exceeds 2 ppb. Considerable controversy and debate have centered on this issue. The drain dischargers contended that the recommendation was based on inadequate research. They also said that providing the volume of fresh water required for alternative habitat recommended in the 1990 Plan would be excessively costly and difficult to implement in the water-short Valley. Significant negotiations and cooperation among dischargers, wildlife interests, and government agencies have occurred in implementing projects and developing information on appropriate alternative and compensation habitat requirements.

In 1993, USFWS and several public interest groups filed an appeal with SWRCB on CVRWQCB's Waste Discharge Requirements asserting that Waste Discharge Requirements were inadequate to protect wildlife using evaporation ponds. SWRCB held an evidentiary hearing in 1995. Meanwhile, USFWS developed compensation and alternative habitat protocols based on the concentration of selenium in waterfowl eggs (USFWS, 1995a, 1995b). The determination of compensation and alternative habitats would take into consideration egg selenium content and other factors, rather than only the concentration of selenium in pond water as suggested by SJVDP. Several pond operators and other parties involved in the appeal signed a settlement agreement to follow USFWS protocols. Table 1D-1 shows the acreage of evaporation ponds, alternative or compensatory habitats recommended by SJVDP and required by CVRWQCB and USFWS protocol, and the settlement agreement. SWRCB released *Petitions Regarding Tulare Lake Evaporation Ponds--Staff Technical Report* (SWRCB, 1996) and agreed with the petitioners that all of the final EIRs inadequately address (1) impacts of trace elements (other than selenium) on birds, (2) negative effects of salinity levels on birds, and (3) impacts of pond closure. In addition, four of the final EIRs inadequately address sub-lethal impacts on birds from exposure to selenium. On March 21, 1996, SWRCB passed a resolution remanding the Waste Discharge Requirements and EIRs of five Tulare and Kern subarea drainers (TLDD; Lost Hills Water District; Rainbow Ranches, Inc.; Stone Land Co.; and Morris & Sons Farms) to CVRWQCB for reconsideration.

As of July 1996, Morris & Sons ceased pond operation. In November 1997, Stone Land Co. entered into a settlement agreement with the USFWS. Of the six operators who previously reached agreement with USFWS on continued pond operation, four from the Alpaugh Group (Martin Ranch, Bowman Farms, 4J Corp., and Pryse Farms) decided to cease pond operations. Britz, Inc., G & C Meyer Farms Inc., Stone Land Co. and Westlake Farms have reached agreement with USFWS and continue pond operation.

In 1998 there are 7 operators of 10 basins covering approximately 4,895 acres. Table ID-2 gives a general time line of the acreage and number of basins. Although the number of basins has decreased from 24 to 10, the surface acreage of ponds has only reduced from 6,715 to 4,895. Of the operators permitted to discharge, the decrease from 17 basins to 10 basins has resulted in a reduction in acreage of about 10% (5,466 acres to 4,895 acres).

Table ID-2. Status of evaporation basins from 1990 to 1998.

Year	No. of basins	No. of operators	Surface area in acres	Disposition
1990	24	21	6,715	
Before 8/6/93	22	19	6,605	Two basins closed
8/6/93	17	14	5,466	Five basins prohibited from discharging
Before 1995	15	12	5,073	Two basins closed and cells closed at LHWD and Meyer
1995	10	7	4,895	Five operators closed basins after settlements

Modified Evaporation Systems

There has been no significant effort in the Valley to develop and implement accelerated rate evaporation systems as suggested in the 1990 plan. The SJVDP did not recommend a specific system but did suggest that lifting and dripping drainage water from elevated perforated water pipes to accelerate evaporation could substantially reduce surface area of evaporation ponds. The USBR conducted a demonstration project with such a system in El Paso, Texas, but the project was not a comparable application. Such a system has not been used in the Valley; lifting the water the required height to ensure adequate evaporation would be energy intensive, and installing, maintaining, and operating the system would be costly. Moreover, confining the wind-blown sprays would be difficult because of Valley winds.

The use of a “solar evaporator” at the Red Rock Ranch and Mendota agroforestry demonstration projects have been tested for the past few years. Drainage water is evaporated in a shallow 2-acre depression lined with plastic. Sprinklers apply a thin film of water during each application to reduce ponding and associated wildlife impacts. This system was modified in 1996 in response to notices of Waste Discharge Permit violations issued by the CVRWQCB for the Red Rock Ranch and Mendota agroforestry projects. The violations were for an approximately two-inch depth of ponding that was sufficient for establishment of brine flies and attractive to nesting birds. Eggs laid in the nests were examined by the USFWS and were found to contain dead and deformed embryos with extremely high concentrations of selenium. Modifications to the sprinkler application rate eliminated ponding in the solar evaporators.

ID. Previous Issues, Not Limited to the Rainbow Report

A widespread need for agricultural drainage in the San Joaquin Valley was recognized as early as 1886, but planning of drainage facilities did not begin until the mid1950's (San Joaquin Valley Interagency Drainage Program Agricultural Drainage and Salt Management in the San Joaquin Valley, June 1979). The 1975 *Water Quality Control Plan for the Tulare Lake Basin* recognized drainage and methods of disposal would be needed to sustain agriculture. The plan anticipated 25,000 acres of land would be displaced by an agricultural drain (~1,200 acres) and land disposal systems (~24,000 acres). It discussed possible environmental effects and concluded that the land displaced could reduce or eliminate top predators and reduce species diversity, thus creating a less stable ecosystem. It also discussed concerns of algal growth, mosquito breeding, and avian botulism outbreaks.

The onset of water projects for importation of water into the Tulare Lake Basin has been both a blessing and a curse. The surface water for irrigation has reduced impacts of ground water overdraft but has also contributed to a salt imbalance. No master drain exists and the current ~4,900 acres of evaporation basins that do exist are not sufficient to sustain agriculture for an indefinite time. The *Water Quality Control Plan for the Tulare Lake Basin, Second Edition*, (Basin Plan) recognizes that almost 400,000 tons of salt are imported into the Tulare Lake Basin each year with only a nominal amount exported. Degradation of groundwater in the Tulare Lake Basin by salts is unavoidable without exporting salts out of the Basin.

The San Joaquin Valley Interagency Drainage Program studied the impacts associated with disposing of drainage water utilizing a drain for export. Environmental impacts identified in the 1979 EIR include the following:

1. Seepage from the drain
2. Spillage associated with flooding
3. Accumulation of toxic or noxious waste (pesticides, nutrients, and sewage)
4. Wildlife impacts
5. Creation of nuisance species (mosquitoes)

The impacts identified in the 1979 EIR relate in some ways to the regulation of evaporation basins. Concerning the issue of seepage, tile drainage removes salts from a large area and concentrates salts without a means for export out of the Basin. Based upon soil types and local conditions any seepage from evaporation basins relative to migration of imported salt and salt leached from the soils is generally considered insignificant. Concerning spillage, the evaporation basins are operated and maintained to prevent inundation or washout due to floods with a 100-year return period. Concerning accumulation of pesticides, nutrients, and sewage, the discharge is limited to subsurface agricultural drainage water. Studies conducted by state and federal agencies from 1986 to

1989 have shown that pesticides are rarely observed in subsurface agricultural drainage. Wildlife impacts are the main focus of studies at evaporation basins. The incorporation of successful mitigation measures for wildlife impacts may result in the use of evaporation basins as a permanent solution.

II. Wildlife Risk-Based Analysis Associated with Evaporation Ponds

The assessment of potential risk of adverse impacts resulting from evaporation basin operations includes consideration of:

1. The numbers and species composition of wildlife, particularly waterbirds, inhabiting the evaporation basins on a seasonal basis.

2. The number of birds nesting at the evaporation basins.

3. Concentrations of selenium in the water, macroinvertebrates preyed upon by foraging birds, bird tissue, and particularly bird eggs.

4. The risk of adverse impacts on reproductive success for those birds foraging and nesting at the evaporation basins, based on population-level toxicological risk associated with dietary exposure and selenium concentrations observed in waterbird eggs.

5. The observed frequency of reproductive impairment including, but not limited to, teratogenesis.

6. Risk of acute and chronic effects on wildlife associated with exposure to elevated concentrations of water quality constituents including, but not limited to, salts.

Additional factors considered in assessing the potential risk of adverse impacts include nest flooding, entrapment of young birds in tires and other materials used for levee stabilization, and mortality resulting from vegetation control and maintenance activities.

Impacts of evaporation basin operations are considered to be significant if they individually or collectively:

1. Increase mortality

2. Reduce growth or condition

3. Result in reproductive impairment

4. Cause post-hatch juvenile mortality

5. Cause or contribute to substantial short- or long-term reductions in species abundance or

6. Contribute directly or indirectly to substantial cumulative effects when viewed with past, current, and reasonably foreseeable future projects.

Toxicity Associated with Evaporation Ponds

Exposure to elevated concentrations of selenium and other water quality constituents has been shown to contribute to the risk of adverse impacts to the health and reproductive success of shorebird and waterfowl species inhabiting agricultural evaporation basins. The risk of adverse effects has been primarily associated with exposure and bioaccumulation of selenium, although other effects associated with water quality constituents have also been identified. The primary areas of concern with regard to selenium exposure at agricultural evaporation basins have focused on reduced health and condition of adult waterbirds, reduced hatchability of eggs, and embryonic deformity (teratogenesis).

A variety of waterfowl and shorebirds seasonally inhabit or utilize evaporation basins. These birds use evaporation ponds as resting, foraging, and nesting areas. The primary focus of investigations of adverse impacts related to exposure to water quality constituents has been on American avocet and black-necked stilt, although consideration has also been given to other breeding and non-breeding waterbirds. As a consequence of differences among species and lifestages in their usage of evaporation ponds, including the duration of residence, diet and foraging patterns, and movement among various geographic areas characterized by different contaminant concentrations, there exist species-specific differences in the exposure and corresponding potential for biological risk among waterbirds utilizing San Joaquin Valley wetlands and evaporation ponds. These and other environmental and biological factors need to be taken into account as part of the assessment of potential risk of adverse impacts associated with evaporation pond operations on wildlife.

Agricultural drainage waters within evaporation ponds contain a variety of constituents that have the potential for affecting waterbirds. Among these constituents the potential adverse effects associated with exposure to elevated concentrations of selenium have received the greatest attention. Academia, resource and regulatory agencies have conducted research on the effects of selenium on waterbirds over the past decade. These investigations have demonstrated that concentrations of selenium within agricultural drainage waters vary among geographic areas and in response to variation in irrigation patterns and other land-use practices. As a result, selenium concentrations within and among evaporation basin systems vary considerably, which must be considered when developing a risk assessment of potential evaporation basin impacts on wildlife.

Research within San Joaquin Valley evaporation ponds, and as part of various laboratory studies, has demonstrated the uptake and bioaccumulation of selenium by a variety of organisms used as food resources by waterbirds. Uptake of selenium from agricultural drainage waters has been demonstrated for plants such as widgeongrass and macroinvertebrates including brine fly and midge larvae, water boatmen *(corixids)* and other invertebrate and fish species (e.g., Mosquitofish). The pathways for selenium bioaccumulation which may ultimately contribute to increased body burdens and adverse effects on waterbirds, including health and condition of adults and reproduction (teratogenesis and mortality), have been the subject of a number of studies. Laboratory experimental studies and statistical analyses of field data have been performed in an effort to identify the relationship between selenium concentrations measured in water and food supplies within evaporation ponds and corresponding thresholds resulting in adverse effects on both the health and reproductive success of various waterbird species. Results of these studies have also shown a relatively rapid depuration rate for selenium.

Toxicological laboratory investigations have demonstrated that the effects of selenium exposure on wildlife vary depending on the chemical form of selenium present. Laboratory studies have shown organic selenium *(selenomethionine)* is more toxic than *selenocystine* or *sodium selenite.* Although various forms of selenium have been demonstrated in laboratory studies to have varying absorption potentials and toxicities, analytical methods available for use in analyzing selenium concentrations within evaporation basin waters are generally limited to information on total selenium without chemical differentiation. Skorupa *et al.* (1992) reported that body burden concentrations of selenium observed in ducks collected at evaporation pond sites generally correspond with laboratory experimental studies on the relationship between dietary concentration and corresponding liver concentrations in mallards fed organic selenium *(selenomethionine).* In the absence of detailed information on the chemical form of selenium within samples collected at evaporation ponds contaminant risk thresholds have been based on total selenium concentration within water, sediment, vegetation, invertebrate and bird egg samples.

Others believe that there is sufficient information to produce predictive relationships between selenium concentration at evaporation basins and the risk of adverse effects and unavoidable losses, particularly direct reproductive impairment of black-necked stilt and American avocet (Skorupa, 1998a). Using the exposure-response curve developed for predicting teratogenesis in Tulare Basin, it was predicted in 1996 that black-necked stilts nesting at the Red Rock Ranch Agroforestry site should have a 50.4% rate of teratogenesis and the observed rate of teratogenesis in a sample of 30 eggs was 56.7% (Skorupa, 1998a). The response curve for the Tulare basin is statistically identical to that obtained for Kesterson Reservoir. This same curve was applied to 14 different study areas in the DOI's National Irrigation Water Quality Program in the western U.S. and the predictions matched what was actually observed in all 14 cases (Skorupa, 1998b).

In regard to selenium speciation as an important area of uncertainty to risk assessment at evaporation basins, several studies have clearly shown that aqueous speciation of selenium does not affect the unit toxicity of selenium that is incorporated in the food chain (Skorupa, 1998b). That is, it does not matter whether selenate, selenite or selenomethionine is present in the water because once selenium moves into the food chain via biotransformation a given water concentration of selenium will have a uniform level of toxicity to consumers of the food chain organisms. Once incorporated into the food chain, there appears to be a universal toxic currency with regard to selenium that is not dependent on original aqueous source speciation, and that removes speciation-related uncertainties for risk assessment. It is possible to measure selenium in the food chain, or in eggs, and very reliably assess risk without ever having to know aqueous speciation of selenium (Skorupa, 1998a).

One approach for assessing potential risk of adverse effects uses waterborne total recoverable selenium for characterizing environmental conditions and potential risk within an evaporation basin. CH2M Hill *et al.* (1993) presents an analysis of the relationship between waterborne selenium, dietary selenium, and the expected frequency of adverse reproductive effects. The use of water quality criteria (e.g., waterborne selenium concentration) as a tool for evaluating potential risk of adverse effects on waterbirds for monitoring evaporation basin characteristics also offers the management opportunity to reduce, to the extent possible, waterborne selenium concentrations through changes in drainwater management and blending with alternative water supplies to reduce risk of adverse effects and improve habitat quality for areas having low selenium concentrations available for use by waterbirds.

Sub-lethal Effects

Exposure of waterbirds to selenium has been shown to contribute to sub-lethal effects that include, but are not limited to, changes in enzyme activity, histological abnormalities including the development of lesions, impaired growth, and increased susceptibility to disease. Sub-lethal effects are likely to adversely effect waterbird growth, survival, and reproductive success. Empirical relationships between waterborne selenium concentrations and the species-specific risk of adverse sub-lethal effects have not been determined. Although sub-lethal effects resulting from exposure to selenium and other drainage water constituents (e.g., salinity) adversely effect individual reproducing and migrating waterbirds, the magnitudes of these impacts on waterbird populations is unknown.

Migrant and Wintering Waterbirds

Evaporation basins are used as resting and foraging habitat by migrant and wintering waterbirds. The duration of migrant and wintering waterbird exposure to the evaporation basins is highly variable. Waterbirds during their migrations or transit from one area to another may be present at the evaporation basin for hours, days, or weeks. Waterbirds, particularly during over-wintering, may also inhabit evaporation basins for a period of months. As a consequence of the varying durations of residence at the evaporation basins the exposure of these waterbirds to selenium and other evaporation basin constituents is highly variable.

The effects of selenium on the health, conditions, physiology, and survival of non-breeding waterbirds inhabiting evaporation basins have not been studied extensively

(CH2M Hill *et al.*, 1993). Studies on selenium body burden in waterbird liver and muscle tissue demonstrate that elevated concentrations of selenium are present at some evaporation basins. Observations by Barnum (unpublished dated) have also shown that some waterbirds wintering on evaporation basins have lower overall body condition, enlarged salt glands, and elevated concentrations of selenium within liver and muscle tissue when compared with birds collected at the Kern National Wildlife Refuge.

Results of laboratory studies (Heinz *et al.*, 1990) have demonstrated that waterbirds rapidly accumulate selenium, but also rapidly depurate selenium when a low selenium diet is available. Rapid depuration of accumulated selenium would help reduce the risk of adverse effects on transient and migratory waterbirds.

Exposure to Other Water Quality Constituents

Water quality constituents other than selenium that have the potential for adverse effects on waterbirds have not been extensively investigated. Skorupa as reported in CH2M Hill et al. (1993) investigated boron and arsenic in waterbird egg and liver tissues within the Tulare Basin. Results of these investigations found that levels of boron and arsenic were below adverse effect thresholds. Ohlendorf *et al.* (1993) reviewed available data and information on potential adverse effects of trace elements, including arsenic, boron, and molybdenum on waterbirds. Concentrations of these three elements observed in waterbird eggs collected at evaporation basins were below levels where embryo toxicity was detected in experimental studies. With specific regard to field-based avian embryotoxicity, the potential interaction among contaminants have been extensively studied and they isolate selenium as the sole chemical factor influencing embryo viability (Skorupa, 1998b). This does not rule out relevance of interaction effects for other response variables such as chick growth rates or adult mortality.

CH2M Hill *et al.* (1993) also report that insecticide and herbicide concentrations in evaporation basin pond water and organisms are at low or non-detectable levels and have therefore not been identified as a significant risk. Other drainage water constituents, including molybdenum, uranium, and vanadium are reported from evaporation basins, however the potential for adverse effects associated with exposure to these and other drainage water constituents has not been determined. Moreover, potential synergistic or additive effects resulting in lethal or sub-lethal responses by organisms inhabiting evaporation basins have not been extensively investigated. After review of the available information CH2M Hill et. al. (1993) state that, “although the potential for interaction effects requires further evaluation, there is no compelling evidence of important interactive or additive embryo toxic effects in the field (Skorupa and Ohlendorf, 1991)”.

Indirect Effects on Other Wildlife

The areas adjacent to evaporation basins are used by a variety of wildlife including, but not limited to, the blunt-nosed leopard lizard, Golden eagles, kit fox, kangaroo rats, northern harriers, red-tailed hawks, black-crowned night herons, snowy egrets, raccoons, skunks, burrowing and short-eared owls, rattlesnakes, gopher snakes, Cooper's hawks, jackrabbits, and cottontail rabbits (Cain, unpublished data). Black-crowned night herons, great egrets, and snowy egrets nesting on the South Wilbur Retention Basin were observed during field studies in 1992 to prey on avocet chicks within both the TLDD South and Hacienda Evaporation Basins (Marn *et al.* unpublished data). Peregrine falcons have been observed foraging at the evaporation basins. Birds have also been observed foraging on insects at the evaporation basins.

Wildlife species inhabiting areas adjacent to the evaporation basins are susceptible to potential indirect adverse effects. Body burden selenium concentrations for waterbird eggs and adult tissues collected at some evaporation basins have been reported at elevated levels. Predation by wildlife species on prey having selenium and other constituent accumulations provides a trophic pathway for exposure of these wildlife species to evaporation basin constituents.

The available scientific information is insufficient to develop a predictive relationship between selenium concentrations occurring at evaporation basins and risk of adverse effects and unavoidable losses. In addition, detailed field surveys have not been performed to determine the relative abundance, usage patterns, foraging activity, or exposure of various wildlife species to selenium at evaporation basins. Due to a lack of available information, no quantitative assessment of risk of adverse impacts to wildlife can be developed. Efforts designed to reduce waterbird usage of evaporation basins are expected to also contribute to a reduction in exposure of predators as a consequence of reduced prey availability.

Salinity Effects

Euliss *et al.* (1989) reported the occurrence of calcium carbonate accumulation on the feathers of ruddy ducks collected within evaporation basins. Accumulation of calcium carbonate on tail feathers adversely effects the bird's ability to fly and avoid predators. Salt accumulation also contributes to a direct increase in the weight of a bird and therefore bioenergetic demand and energy expenditure for movement, which is expected to be reflected in reduced health and condition. Salt encrustation has also been found to structurally damage the integrity of the feathers. Although salt encrustation represents a risk of adverse effects on the condition and survival of individual ducks, the overall significance of adverse impacts is unknown.

Salinity levels observed within evaporation basins may contribute to reduced hatching success and increased juvenile mortality. Exposure to saline waters has been suggested as one of the causative factors contributing to low hatching success for eared grebes nesting at several evaporation basins. Consistent exposure of ducklings to saline waters has also been reported to result in physiological stress, reduced growth, and increased mortality. Availability of a source of freshwater shortly after hatching has been reported as an important factor in reducing sub-lethal and lethal effects on young ducks. Observations at TLDD evaporation basins during the spring and summer of 1992 showed a movement of ducks from areas having higher salinities to inlet areas where EC and TDS concentrations are reduced (TLDD unpublished data).

Entrapment

Young waterbirds are vulnerable to being entrapped within the center well of vehicle tires used to help stabilize some evaporation basin levees. Entrapment by waterbirds within the tires contributes to an increase in mortality, however the population impacts of this increased mortality are unknown. In recognition of concerns expressed regarding entrapment of young waterbirds pond operators have removed tires from evaporation basin levees.

Waterbird chicks have been also become entrapped within phosphate foam that accumulates along evaporation basin shorelines. The significance of these adverse effects is unknown.

Avian Disease

Mortality to waterbirds as a consequence of avian botulism has been observed within the San Joaquin Valley. Avian botulism has been associated with the accumulation of large numbers of waterbirds within areas where shallow, warm waters occur during spring and summer months. Mortality associated with avian cholera, although not as extensive as that reported for avian botulism, has been reported for the San Joaquin Valley. Resource agencies have required disease surveillance and the removal and disposal of dead or dying waterfowl observed at evaporation basins.

Nest Flooding

Waterbirds nesting on windbreaks and evaporation basin levees, as well as within dewatered evaporation pond cells, are susceptible to mortality resulting from nest flooding as a consequence of water level fluctuations. Flooding of established waterbird nests has been observed within several evaporation basins (Cain, unpublished data). Nest flooding represents a source of mortality directly associated with evaporation basin operations.

Predation

Predation has been identified as a major source of mortality of nesting waterbirds at evaporation basins. Configuration of the interconnected pond cell levees allowing predators easy access to ground nests is probably a key factor in the high rates of predation observed. Predators include coyote, raccoon, and snakes. Estimates of nest predation for black-necked stilt and American avocet (Skorupa, unpublished data) at the Lost Hills Water District Evaporation Basin show that the mean unweighted predation rate is 53% for stilt and 40% for avocet for the period from 1987 through 1991. Nest predation varied substantially between years, however, for both black-necked stilt (10.5 to 84.2%) and American avocet (1.7 to 97.0%) (Skorupa, unpublished data). High nest failure on levees and non-isolated windbreaks has also been observed at other evaporation basins, with predation identified as a leading cause of nest failure. The incremental increase in predation mortality attributable to waterbird nesting at evaporation basins has not been evaluated.

Maintenance Activities and Disturbance during Nesting

Concern has been expressed regarding potential adverse impacts on waterbird reproductive success (egg hatching) as a consequence of hazing and disturbance during egg incubation. Hazing and disturbance of adults after nesting has occurred identifies the location of the nest to predators and exposes incubating eggs to potentially adverse solar heating which may contribute to reduced hatchability or embryonic deformity. The significance of disruption of nesting adults on reproductive success and mortality rates has not been documented through field investigations.

Field observations by Skorupa and Cain (unpublished data) have shown that waterbird nests have been destroyed as a consequence of vegetation control activities performed at evaporation basins. Vegetation control includes both chemical treatment and mechanical removal (grading). Additional grading occurs at the evaporation basin facilities in association with levee maintenance. Disturbance during nesting associated with vegetation control, including grading, is an incremental source of mortality.

Evaporation basin operators have recognized and are sensitive to adverse effects resulting from disturbance during nesting. In response to these concerns levee maintenance activity is scheduled to avoid disturbance of nesting waterbirds. Maintenance schedules are adjusted based on seasonal patterns in waterbird nesting and direct field observations of waterbird nesting within various areas of the evaporation basin complex.

Summary

Based upon the scientific information currently available, risk based analyses of potential adverse impacts of evaporation basin operations has shown:

1. Waterborne selenium concentration within some evaporation basins are below a threshold where the risk of adverse impacts to wildlife are considered to be less-than-significant.

2. The assessment of potential risks of adverse impacts associated with evaporation basin operations requires site- and species-specific analyses according to some while others do not think site-specific-ness is needed. To date, reliable risk assessment has been developed for two species of birds (black-necked stilt and American avocet.

3. A number of uncertainties exist in evaluating potential biological risks associated with exposure to selenium within evaporation ponds including, but not limited to, the form of selenium with a pond system, sub-lethal exposure effects, effects of short-term exposure on migratory waterbirds, variation among sites in the biological response of various species to waterborne selenium concentrations, and other issues relevant to a risk-based assessment of potential adverse impacts. Aqueous speciation of selenium, according to some, is not an important risk parameter and total selenium is adequate.

4. Concern exists regarding potential risks associated with waterbird exposure to water quality constituents other than selenium however; empirical relationships have not been developed for these constituents for use in assessing potential risk

Other factors, such as predation, nest flooding, entrapment, disease, and disturbance represent potential risks to wildlife at evaporation basins but must be evaluated on a site-specific basis as part of a risk-based assessment of potential adverse impact to account for variation in facility design and operations.

III. Systems Integration of Evaporation Ponds in Drainage Management

IIIA. Out-of-Valley Options for Drainage Impacted Lands

Implementation of an out-of-valley management option would require the integration of a number of in-valley drainage management measures. It is unlikely that subsurface agricultural drainage could be discharged out of the valley without some form of pretreatment and/or volume reduction (evapoconcentration), particularly for a discharge location in the San Francisco Bay or Sacramento-San Joaquin Delta. These could consist of evaporation ponds, agroforestry plantations (reuse), enhanced evaporation facilities, wetlands treatment, or other physical, chemical or biological treatment. A major feature of a valley-wide drain would be regulating reservoirs. The IDP (1979) developed a recommended plan that contained 7,600 acres of regulating reservoirs. The plan also contained 45,300 acres of marshes and 19,000 acres of influent/effluent reservoirs for the marshes. Marshes were not considered as treatment facilities in the IDP plan but as reuse opportunities for the drainage. In any future integration of systems containing an out-of-valley component, all such facilities would likely serve multiple purposes including volume reduction, flow regulation, reuse, treatment and, possibly, habitat.

There are numerous possible combinations of systems for an out-of-valley option, though the (technical) feasibility of some has not been proven. The development and implementation of an out-of-valley option would be a major undertaking. The integration of evaporation systems with this option would be determined during the environmental planning process in consideration of the technical, scientific, regulatory, social, and economic factors related to the project as a whole. Limitations on the discharge would likely be the controlling factor to the integration of the other components.

One out-of valley option would not involve conveyance in an open channel but in a pipeline. This would require considerable volume reduction (through evaporation) before discharge to keep pipe sizes reasonable. The capital cost of a pipeline would probably be less than an open channel due to lower right-of-way costs and costs of reservoirs and appurtenant structures. Operational costs could be more or less, depending on flow rates and operating pressures.

The ultimate feasibility of any out-of-valley option will depend more on the social and institutional acceptability of the proposal than its technical feasibility. Previous proposals have historically generated considerable controversy, with the result that none of them has ever been completed.

IIIB. Partial Treatment Before Discharge into Evaporation Ponds

Introduction

The treatment of agricultural drainage water to reduce the hazard to wildlife has largely focused on selenium removal. If the Se concentration can be reduced in the drainage water, the toxicology hazard will be greatly reduced. Basically, three methods have been tried to remove Se from subsurface drainage water: anaerobic microbial cultures, phytoremediation using flow-through wetlands and microalgae, and chemical reduction using iron compounds and iron metal. Additional information is available in the report of the Technical Committee on Drainwater Treatment. All of these methods have had limited success and are all being studied currently to improve their performance and reliability.

However, the hazard of evaporation ponds to waterfowl extends beyond selenium toxicosis. There are other toxic trace elements and potentially toxic chemicals found in drainage water. For example, elevated concentrations of uranium, vanadium, boron, arsenic, chromium, and molybdenum have been identified (Tanji, 1989; Chilcott, et al. 1990; Bradford et al., 1990; Amrhein et al. 1993, Amrhein et al. 1997). Several of the methods for selenium removal that have been studied can simultaneously remove some of these other trace elements. Uranium, chromium, molybdenum, and vanadium can be reduced to lower oxidation states, which are much less soluble, under anaerobic conditions. Treatment processes that rely on anaerobic conditions for Se reduction and precipitation or adsorption will frequently remove these elements as well. Iron compounds and zero-valent iron will reduce and precipitate selenate, uranyl, and chromate to very low concentrations. There is hope that this method, which has been tried at the pilot scale, can be perfected and used as a polishing treatment following microbial reduction.

Boron is largely unaffected by changes in redox status and tends to concentrate in the ponds (Tanji, 1989) although its toxicity to waterfowl is considered low. Elevated boron concentrations may be the single most important factor limiting drainwater reuse for irrigation (see the section on agroforestry).

In addition to the elevated concentrations of trace elements, drainage water is high in fertilizer residues and agricultural chemicals. The fertilizer nutrients in the drainage water lead to eutrophication in the ponds with accompanying growth of dense algal mats and microalgae. Treatment technologies that remove nutrients, in addition to selenium, will reduce eutrophication and this is considered an added benefit. Treatment systems using flow-through wetlands have this potential.

The concentrations of agricultural chemicals, like soil fumigants, insecticides, fungicides, and defoliants, to mention a few, are largely unmeasured in the evaporation ponds. There is evidence that on two occasions, high concentrations of a pesticide or herbicide in the drainage water may have killed microbial populations in an anaerobic biological reactor (Hanna et al., 1990).

Treatment Methods

A detailed discussion of drain water treatment methods, field trials, and relative costs was the focus of a report by Hanna, Kipps, and Owens (1990), submitted to the San Joaquin Valley Drainage Program, Sacramento, CA. Here we summarize the findings of this report and in a few cases add new findings. The methods to reduce selenium loading to evaporation ponds or to the San Joaquin River can be grouped into biological treatment and chemical treatment. Biological treatment processes include anaerobic bacterial reactors, algal/bacterial ponds, anaerobic soil columns, enhanced microbial volatilization of Se from soils, ponds, and salt-tolerant plants, and flow-through wetlands. Chemical treatment processes include desalinization using reverse osmosis (RO) membranes, chemical reduction using Fe(II) salts or iron metal (zero-valent iron), adsorption, and ion exchange. In both biological and chemical treatments, filtration of the product water may be necessary to remove precipitated selenium.

Biological Treatment Methods

<u>Anaerobic Microbial Treatment</u>

The reduced forms of selenium are significantly less soluble than the oxidized species so there has been an intense search for anaerobic treatment processes that take advantage of this. Several pilot-scale projects that use anaerobic reduction reactions to precipitate Se from drainage water have been tested. These treatment processes vary based on reactor design and the type of carbon source and nutrients provided to the microorganisms. Reactor designs include above ground tanks containing sludge beds, fluidized beds, or fixed films; deep and shallow ponds; saturated soils; and vegetated wetlands. The carbon sources that have been studied include methanol, Steffens waste from sugarbeet processing, acetate from acetic acid, molasses, and algal cells grown in a shallow ponds, killed, and fed to bacteria in an anaerobic sludge-blanket reactor. In general, nitrate and oxygen tend to retard the reduction process, so biological denitrification to remove NO_3^- and O_2 has been suggested as a pretreatment. All biological treatment processes are enhanced under warm conditions, so removal efficiencies are generally better in the summer. Variations in input water quality can drastically affect reactor performance, so constant monitoring is required. In general, biological reactors appear promising, being both efficient at removing Se and cost effective. Costs for biological treatment are estimated to range from $70 to $300 per acre-foot of water (Hanna et al., 1990).

Flow-through Wetlands

There is evidence that significant losses of Se, through biologically mediated methylation and volatilization, can occur in wetlands. The toxicity of the volatile Se compounds, such as dimethylselenide (DMSe), are 600-700 times lower than the inorganic forms (Karlson and Frankenberger, 1990). Finding the conditions that are optimum for volatilization has been one of the goals of constructed-wetland studies. Concerns over low volatilization rates of DMSe from aquatic systems and the gradual accumulation of Se in the sediments and vegetation may limit this method. The attractiveness of this method is the low cost and large volumes of water that could be treated. The biggest concern with wetland treatment systems is the potential use by waterfowl and the similarity to the conditions that existed at Kesterson Reservoir.

Currently, a pilot project in the Tulare Lake Drainage District has been set up to evaluate the effectiveness of constructed wetlands to remove selenium from drainage water. The ten ponds (each 50-ft x 250 ft) were flooded and planted in the summer of 1996. Various species of wetland plants are being studied including saltmarsh bulrush, Baltic rush, smooth cordgrass, rabbitsfoot grass, widgeon grass, and cattail. One of the ponds is unplanted as a control. Surface water, sediment pore water, plant tissue, and sediment samples are being collected monthly to determine the removal efficiency, fate of selenium, and the oxidation state of water soluble Se (Terry, 1997). Plexiglas chambers that cover whole plants are being used to monitor Se volatilization rates. Preliminary data suggest that 18% to 70% of the incoming Se is being removed from the drainwater through various sink mechanisms. See Section VA for further details. Work is ongoing to determine the relative partitioning of Se into sediments, plant biomass, and gaseous losses (Terry, 1998).

In conjunction with this field-scale project, a mesocosm-scale project is ongoing in at UC Riverside. This project is designed to address some of the shortfalls of the field-scale project, which include non-replication and an inability to measure leaching losses. The mesocosm wetlands consist of polyethylene drum-halves linked in series and filled with 30 cm of soil. Three drum-halves were linked in a cascade design to represent the beginning, middle, and end of a long, narrow wetland cell. Twelve mesocosm series allowed for 4 treatments with 3 replications. In the first part of the study, the treatments were cattails, rabbitsfoot grass, a shallow water control, and a deep-water control (no vegetation). Preliminary analysis of the influent and effluent indicates that the cumulative selenium load was reduced by 42% in the vegetative treatments and 28% in the non-vegetative treatments. No significant difference in total selenium reduction was observed between the two vegetation types (Parker et al., 1997). Preliminary results on the non-vegetative treatments suggest that about half of the loss could be attributed to volatilization, but a more recent mass balance indicates about a 10% shortfall attributed to gaseous losses (Parker et al., 1998).

Chemical Treatment Methods

Desalinization

The direct removal of salts from drainage water using reverse osmosis could reduce the size of the evaporation ponds, but disposal of concentrated brine will still be needed. Reducing the volume of water that requires evaporative disposal reduces the size of the ponds and minimizes the use by waterfowl. In the 1990 "Management Plan" there is mention of a drainage-water desalting demonstration project at Los Banos. The California Department of Water Resources from 1983 to 1986 operated this facility. Desalinization requires extensive pretreatment of the water to reduce scaling and biological fouling prior to reverse-osmosis with semi-permeable membranes. Westside agricultural wastewater is particularly high in calcium sulfate, silica, and suspended solids. Pretreatment process that have been evaluated include: lime-soda ash softening, ion exchange softening, and biological pretreatment using flow-through wetlands followed by gravity filtration. High quality product water could be produced with about 75%- 88% recovery. The TDS of the product water ranged from 550 to 650 mg/l and the Se concentrations were <15 ug/L. Boron was more difficult to remove, with about 50% making it past the RO unit and concentrations of ~8 mg/L in the product water. Disposal of the saline brine (containing over 1000 ug/L Se) from the RO membranes and the brine used to regenerate the ion exchange membranes was still required. It was concluded that treatment costs exceeded $1000/af if the brines could be disposed of in Class II ponds. The high cost of pretreatment, equipment, maintenance, power, and waste disposal makes desalinization an unlikely option (Hanna et al. 1990).

Chemical Reduction Using Iron-based Reactants

Iron fillings (zero-valent iron) can be used to remove selenium from water. The iron acts as both a catalyst and reductant (electron donor) for the reaction. The selenium is reduced to selenite, Se(0), and selenide depending upon pH and O_2 of the water. Low pH and low oxygen favors the more reduced forms of selenium. In 1985, Harza Engineering Co. tested a pilot-scale process using iron filings in flow-through beds. The testing was discontinued because the beds quickly cemented with precipitates. The study did not conclusively identify the oxyhydroxide precipitates but recent work suggests that "green-rust" ($Fe^{II}_4Fe^{III}_2(OH)_{12}SO_4 \cdot nH_2O$) may be the initial precipitate, which is then oxidized to magnetite (Fe_3O_4) by nitrate and oxygen (Hansen, et al. 1996; Myneni, et al., 1997). Other likely precipitates include siderite ($FeCO_3$) and ferrihydrite ($Fe(OH)_3$). The advantage of zero-valent iron is it can reduce the concentration of Se to very low concentrations and might be useful as a polishing step following microbial treatments. If the wastewater is anaerobic as a result of the microbial treatment, the formation of secondary precipitates is minimized (unpublished data, Roberson and Amrhein).

Salts of Fe(II) can effectively reduce selenate to selenite and the resulting Fe(III)-hydroxide acts as a strong adsorber for the reduced selenium. This treatment method may require pH adjustment for optimum precipitation of the ferric hydroxide and the ferric hydroxide sludge may be classified as hazardous waste if the Se concentration is high. The cost of reagents and sludge disposal is of concern, limiting the usefulness of this process. Both iron salts and iron metal treatment process can remove Se for about $120/acrefoot (Hanna et al., 1990).

Ion Exchange Resins

Ion exchange has been tried for selenate removal from water but the problem of sulfate competition for exchange sites has not been solved. However, a new carbon aerogel membrane appears to be able to adsorb selenium, nitrate, boron, and major ions including sulfate (Davis et al, 1998). Development of a selenate-specific ion exchanger would be desirable.

IV. Pond Management Options: Present Status of Active and Inactive Ponds

IVA. On-site and Off-site Mitigation Actions Taken by Pond Operators since 1990

Prior to 1989, evaporation basins were regulated by waste discharge requirements or by waiver of those requirements (WDR). This changed when studies conducted by the U.S. Fish and Wildlife Service revealed adverse impacts to wildlife occurring at evaporation basins in the Tulare Lake Basin. In 1989, when the Board circulated tentative WDR comments received from DFG and others prompted the Board to develop an EIR addressing cumulative impacts. During this period, actions to mitigate for wildlife consisted of primarily Department of Fish & Game (DFG) mitigation agreements with operators. The DFG agreements spelled out measures to reduce impacts to wildlife. The measures included: minimum water depth of 2 feet, levee slopes as steep as practicable, vegetation control, no construction of exposed windbreaks, disease surveillance and control program, invertebrate sampling, and hazing.

In 1993, specific mitigation measures were incorporated into WDRs that were issued for all evaporation basins in the Tulare Lake Basin. The WDRs allowed discharge for 14 operators and prohibited discharge for five operators (Table IVA-1). Measures to mitigate for wildlife impacts were required and specified in WDRs for those allowed to discharge. Measures included on-site mitigation efforts such as:

1. Basin reconfiguration

    a. Steepening sideslopes to 3:1

    b. Windbreak/island removal

    c. Tire removal

2. Vegetation control

3. Water depth management (2 feet minimum depth)

4. Hazing

5. Disease control

Also, off-site mitigation measures include:

1. Alternative habitat

2. Compensation habitat

3. Agroforestry studies

4. Treatment studies

5. Demonstration habitat

6. Drainage operation plans

Most of the smaller basin operators have decided to cease discharge and close their basins. Only seven operators of ten evaporation basins remain in the Tulare Lake Basin. Of the original 7,000+ acres there still remains about 4,900 acres. Of the seven remaining operators four have settled with petitioners and three are preparing EIRs to address relevant CEQA issues as directed by the State Water Resources Control Board. Also, as part of the WDRs, basin operators were required to submit mitigation assessment reports to evaluate the effectiveness mitigation measures implemented. The mitigation assessment reports are critical to the update of WDRs and for the new EIRs.

VB. Requirements for pond closure

The regulations for closing classified waste management units are described in §20950-§21450 and §21769 from the requirements of Consolidated Regulations for Treatment, Storage, Processing, or Disposal of Solid Waste, as set forth in Title 27, California Code of Regulations, Division 2, Subdivision 1, Section 20005, et seq., (hereinafter Title 27). The appropriate sections for guidance include; Article 2, which describes closure and post-closure maintenance, Article 3, closure standards for units other than landfills, and §21769 which describes closure and post-closure maintenance

Table IVA-1. Present status of evaporation ponds.

Basin	Status	WDR	Acreage	WDR #
4	Inactive, closing	prohibit discharge	120	93-165
5	Update WDRs in 1997	allow discharge	25	97-226 (93-150)
6	Update WDR’s in 1998	allow discharge	210	98-229 (93-156)
8	Update WDRs in 1997	allow discharge	260	97-263 (93-138)
9	Update WDR’s in 1998	allow discharge	59 (21 inactive)	98-182 (93-158)
10	Closed	rescinded	95	95-138 (93-162)
11	EIR pending	allow discharge	301	93-136
12	Update WDRs in 1997	allow discharge	740	97-263 (93-138)
13	Inactive	prohibit discharge	640	93-163
14	Inactive, closing	allow discharge	80	93-140
15	Inactive, closing	allow discharge	15	93-142
16	Inactive, closing	allow discharge	35	93-144
17	Inactive, closing	allow discharge	13	93-146
18	Closed	prohibit discharge	7	95-229 (93-164)
19	Inactive, closing	allow discharge	25	93-148
21	EIR pending	allow discharge	1,026	93-136
22	EIR pending	allow discharge	1,829	93-136
23	EIR pending	allow discharge	345 (197 inactive)	93-152
24	Inactive	prohibit discharge	180	93-166
25	Inactive, closing	allow discharge	90	93-160
26	EIR pending	allow discharge	100	93-154
28	Closed	prohibit discharge	7	96-192 (93-167)

plan. The first step in closing a surface impoundment is to remove all free liquids. Closure then may proceed in one of two ways:

1. Clean-close - all residual wastes completely removed and discharged to an appropriate waste management unit. If, after reasonable attempts to remove all wastes, the discharger can demonstrate removal is infeasible then the basin shall be closed as a landfill pursuant to §21090.

2. Close in place - all residual wastes compacted and the basin closed as a landfill pursuant to §21090.

Landfill closure requirements are described in §21090 of Title 27. In general, §21090 explains final cover requirements, grading requirements, and post-closure maintenance requirements. The final cover must be at least one foot and have permeability of $1x10^{-6}$ cm/sec or less. In addition, a soil cover of at least one-foot must be placed on top of the cap with a vegetative cover to prevent erosion and maintain the integrity of the cap. The final cover must be graded to prevent ponding and to provide slopes of at least three percent. The bottom of the final storage area must maintain a five-foot separation with groundwater.

Findings in the waste discharge requirements state that the discharge can be exempted under Section 20090 (b) of Title 27. However, the sediments that remain at the time of closure may need to be regulated under Title 27. The sediments need to be compared to "background" soil conditions to determine the potential impact to beneficial uses of underlying groundwater and potential nuisance conditions of blowing salts. Even if evaporation basin sediments are exempted from Title 27, in order to properly close, Title 27 must be considered for guidance.

Strategy for closure

Closure of the basin may not affect any beneficial uses of any groundwater. The constituents that have concentrated in evaporation basins are usually naturally occurring and have been flushed from salts occurring within the local soils due to the irrigation of crops. Typically, no waste from outside areas is brought in and the basin closure should have no appreciable effect upon the environment beyond, which was already present in the local area.

Basin closure needs to progress through an administrative process whereby the accumulated sediments from operation of the basin can be demonstrated to be non-hazardous. The closure process should also address the potential impacts to wildlife (i.e., waterfowl and shorebirds) and impacts of PM-10 emissions from blowing dust.

Methodology for closure

A. First step of Evaporation Basin Closure

Collect statistically representative samples of cells and compare to background levels.

B. If the sediments are at or below background concentrations, then

1. Compact each cell to minimize subsidence and the ponding of rainwater.

2. Vegetate the cells to minimize wind and water erosion.

C. Evaporation Basin Closure - Elevated Sediments in Cells

The elevated evaporation basin sediments can be closed in-place by the following method:

1. Level the basins with levee soils and other available soils. This will serve as the closure cover for each cell and needs to be at least 1 foot thick or greater over in-place basin sediments.

2. Compact each cell cover to minimize subsidence and the ponding of rainwater.

3. Vegetate the cover to minimize wind and water erosion.

4. Obtain a deed restriction to limit the activities occurring on the cells to prevent seepage.

D. Evaporation Basin Post-Closure Monitoring

Post-closure monitoring will consist of performing an annual inspection to ensure compliance with the following maintenance program:

1. Observe the integrity of each cell cover. Place additional soils as needed to maintain the minimum one-foot thickness. Fill in any areas of subsidence to prevent the ponding of rainwater.

2. Maintain the vegetative cover to minimize erosion.

The method of closure and post-closure monitoring must minimize the effects to the environment by preventing wind blown basin sediments from being transported off-site, limiting access of waterfowl and shorebirds to the basin sediments, and preventing any substantial impacts to groundwater quality.

V. ON-GOING INVESTIGATIONS RELATED TO EVAPORATION PONDS

VA. Flow-through Wetlands

The principal contaminant of concern to wildlife in waters of evaporation ponds is selenium (Ohlendorf et al., 1993). The San Joaquin Valley Drainage Program invested heavily on treatment technologies to remove selenium and other toxicants in drainage waters. A number of promising technologies have been identified but only the anaerobic-bacterial treatment process has approached the pilot stage reducing selenium from about 300 ppb to about 20 to 50 ppb (SJVDP, 1990). Other technologies still being investigated in a major way include the algal-bacterial system. These treatment processes, so far, do not remove selenium to sufficiently low concentration levels so as not to impact wildlife when the treated water is impounded in evaporation basins.

In the spring of 1997, the Tulare Lake Drainage District, UC Salinity Program and Department of Water Resources have jointly launched a pilot project on flow-through wetland system to remove selenium from drainage water before discharge into evaporation ponds. This approach was successfully used in constructed wetlands located next to San Francisco Bay to remove selenium to low concentrations (about 5 ppb) by passing wastewaters from oil refineries through vegetated wetlands and discharge into the

Bay (Hansen et al., 1998). The selenium removal mechanisms include microbial and plant volatilization of DMSe, microbial and chemical reduction to elemental form, and adsorption of selenite on reactive mineral and organic surfaces, and plant uptake. Other potential sinks include seepage losses. However, about 10 to 30% of the waterfowl nests suffered from Se teratogenesis (Skorupa, 1998a). The Chevron wetland system has been shutdown due to unacceptable high concentration of selenium in waterbird eggs and seepage to neighbors (Skorupa, personal communication).

Figure VA-1 shows the plot layout of the flow-through system at TLDD. The cells are 50 ft wide and 200 ft long, and contain a number of plant species with a control cell (Cell 3). TLDD drainage water is pumped into the cells through metered inlets and outflow is estimated by v-notch weirs. The water depth is variable depending on the plant species ranging from 4 to 24 inches in depth. ET is estimated using an evaporation pan and crop coefficient, and seepage is estimated by difference. Residence time of the water in the cells is being varied to obtain optimal selenium removal.

The applied drainage water contains about 20 to 40-ppb total selenium (Tanji et al., 1997). The predominant form of selenium in the applied water is selenate (Se VI), about 92% of the total selenium, along with selenite (Se IV) and organic selenium (Se II-). The outflow also contains predominantly selenate, from less than 76 to 94% of the total along with selenite, 7 to 28% (except Cell 3 had 58%) and organic selenium, 0 to 6%.

The selenium being removed from these cells in the first season were highly variable because the resident times were too short, less than 3 days, and insufficient biomass and organic detrital matter to support optimal microbial biomass. In the second year of operation (1997), the residence time was lengthened to 7 to 21 days. The percent selenium removal from the cells ranged from about 60% in Cells 9 and 7, about 40% in Cells 10, 5, 2 and 1, and less than 30% in Cells 8, 3, 4 and 6. These percentage values are based on concentration of selenium discharged from the cells as compared to the concentration of selenium in the inflow water that averaged 22 ppb. It was anticipated that the cells would perform better when the vegetated system reaches maturity.

Table VA-1 shows the performance of the cells during the summer of 1998 (Tanji et al., 1998). The data presented is the average for the period July 14 through September 11, 1998 when the average inflow Se concentration was 13.5 ppb. Se outflow on a mass ratio as well as concentration ratio is reported. Mass is defined as concentration x volume. The concentration level of Se in the outflow for some cells is about 4 ppb, slightly more than the target value of about 2 to 3 ppb. These results show promise that selenium can be removed quite economically utilizing flow-through vegetated wetland cells. There is, however, potential danger to birds from selenium poisoning in the wetlands and an avian monitoring program is being established.

Table VA-1. Summary on the performance of wetland cells for the period July 14 through September 11, 1998.

Cell	Vegetation	Residence time days	Se Outflow to inflow ratio on mass basis	Se Outflow to inflow ratio on concentration basis	Average Se concentration in outflow*
1	Saltmarsh bullrush	6.5	0.096	0.53	7.0
2	Baltic rush	8.0	0.26	0.32	4.3
3	Open	7.1	0.52	0.83	11.1
4	Smooth cordgrass	6.7	0.33	0.38	4.9
5	Rabbit footgrass	5.0	0.57	0.79	7.6
6	Nypa forage/saltgrass	8.6	0.23	0.41	5.6
7	Cattail	8.7	0.43	0.34	4.4
8	Bullrush/Ruppia	19.7	0.065	0.54	7.4
9	Cattail/Tule/Ruppia	19.5	0.33	0.49	6.6
10	Cattail (deep water)	12.0	0.17	0.31	4.0

* Average Se concentration in the inflow was 13.5 ppb with a range of 10.9 to 15.3 ppb.

VB - Algal Bioremediation

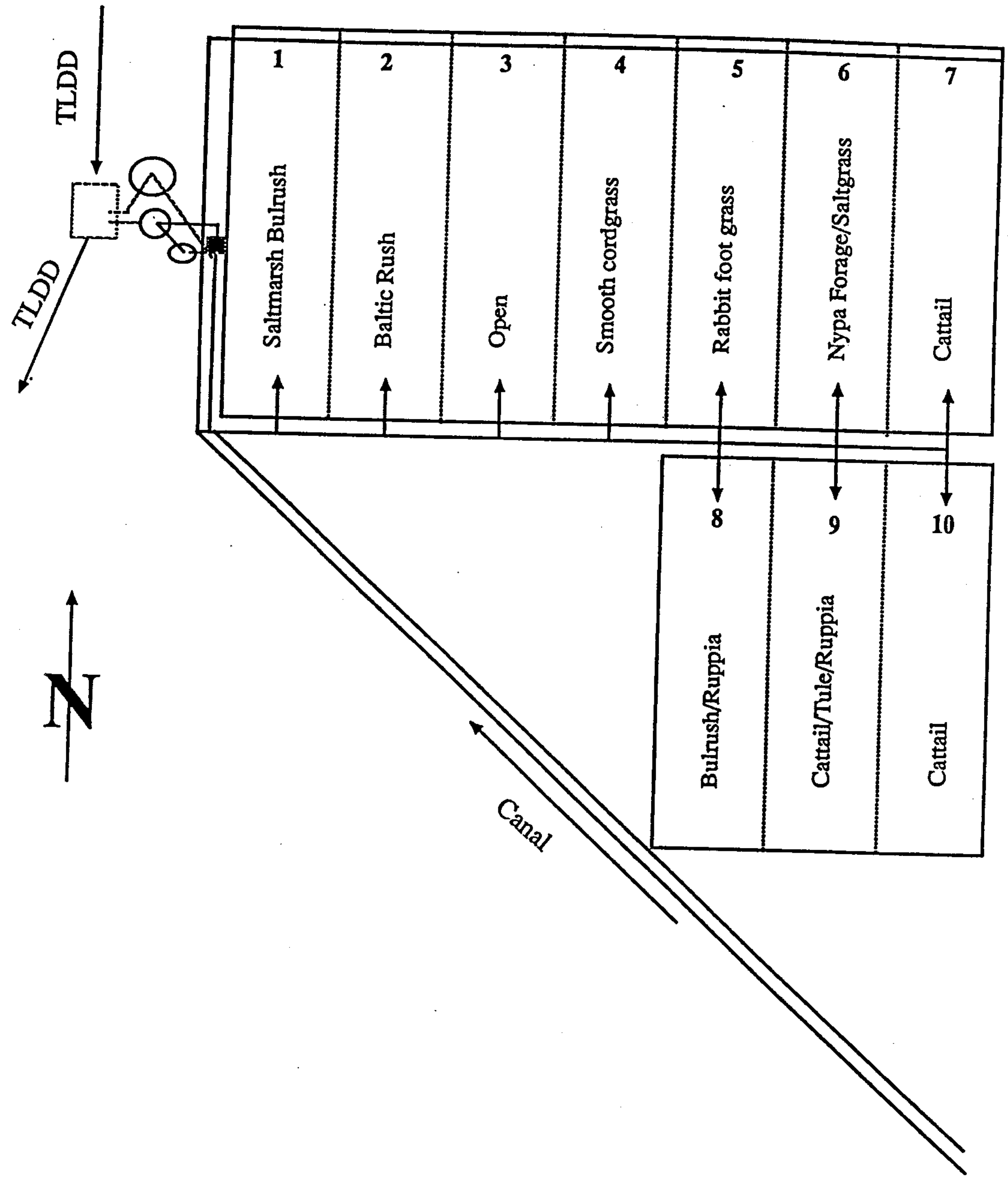
Definitions

"Algal bioremediation", as used in this document, must be defined. The term "algal" is construed to mean any fully aquatic, light-dependent biological process, where direct light input is a required part of the process; thus, "algal" in this section is not restricted to photosynthetic organisms nor to single-species processes. This broad definition was adopted in order to cover the widest range of current and past technologies and research efforts in this area. The term "bioremediation" means the mitigation of deleterious environmental effects, using biological processes.

The Focus of Remediation Efforts in the SJV Evaporation Ponds

In the San Joaquin Valley evaporation ponds, the principal purpose of remediation has been - and still is - alleviating the foodchain ecotoxic effects of selenium in evaporation ponds. Issues involving other toxicants, constituents or salinity in evaporation ponds does not appear to be considered for treatment by algal bioremediation processes as of this writing. Therefore, the nature of the problem to be solved via bioremediation must be covered very briefly here. For members of the animal kingdom,

Figure VA-1 TLDD flow through wetland cell system (Tanjii et al. 1997)



selenium is both an essential nutrient and a toxicant, exhibiting a narrow margin between nutritional requirement and toxic effects. Waterborne and sediment Se bioaccumulates readily into the aquatic biota (from primary producers to top predators) with concentration factors of 1,000 or higher (Ohlendorf, 1997; Maier and Knight, 1994). The extent of bioaccumulation depends on the route of exposure (e.g. diet, water, or sediment) and chemical form of Se (Besser et al., 1993; Maier and Knight, 1994). In Se-laden aquatic environments, chronic toxicity resulting from dietary Se uptake through the foodchain represents a far greater problem than acute toxicity associated with direct water exposure (Maier and Knight, 1994). This ecotoxic chronic Se toxicity is, to an extent, related to the combination of waterborne Se concentration and Se bioaccumulation, as shown for the Kesterson Reservoir and other evaporation basins of the San Joaquin Valley (Skorupa and Ohlendorf, 1991).

However, this relationship is not generally applicable to all aquatic environments and many cases have been reported where waterborne Se concentrations, Se bioaccumulation, and biological impacts did not correlate reliably (e.g., Hamilton, 1997; Hamilton et al., 1997; Canton and Van Derveer, 1997; Lemly, 1993; Adams et al., 1997). For instance, a drastic decrease in Se content in avian eggs was recently observed at the Rainbow Ranch evaporation pond (Kern County, CA) after a moderate dilution of waterborne Se concentration with fresh agricultural tail water (Anthony Toto, CVRWQCB and Des Hayes, CDWR, personal communication).

Consequently, there is a general consensus (Adams et al., 1997) that the complex Se biogeochemistry, particularly biotransformed Se forms in food organisms, may be the key to chronic Se effects expressed in the top predators such as fish and birds. Since Se biogeochemistry varies with site conditions (e.g. fast-flowing river versus slow-flowing wetlands), the need for site-specific water quality criteria was urged (Adams et al., 1997). Moreover, a departure from using water concentrations, that is, sediment-based water quality criteria, has also been proposed (Canton and Van Derveer, 1997). Maier and Knight (1992) summarized precautions regarding the indirect connection of waterborne Se to ecotoxic effects specifically for Central Valley evaporation ponds. These views that waterborne Se concentrations alone would be inadequate in assessing the Se impact on aquatic community, was recently emphasized by a nine-member expert panel in a recent "Peer Consultation Workshop on Selenium Aquatic Toxicity and Bioaccumulation" held by the US Environmental Protection Agency, May, 1998.

Algal Bioremediation Studies

In light of the consensus view that remediation involves complex, site-specific Se biogeochemistry, algal bioremediation efforts in the SJV evaporation ponds appear to be in its infancy. Although there are several algal studies with the stated goal of selenium removal from water (see next section), it is clear from the preceding discussion that remediation involves far more than removal. The very definition of "remediation" demands that a process must reduce the factor(s) controlling the ecotoxic effects of Se. Unfortunately, it was also revealed above that such factors(s) are not well understood. The events of the Rainbow Ranch case cited earlier may lead to a crucial breakthrough if, in fact, it has exhibited an alteration of significant ecotoxic factor(s). For more information, see sections on Rainbow Ranch Invertebrates in this report, and In Situ Treatment Technology and Se Biotransformations by Biological Systems in the Report from the Technical Committee on Drainwater Treatment.

Recent algal studies at UC-Davis, that have expressed long-term goal of reduction of ecotoxic effects, have begun to survey the selenium biogeochemistry of naturally occurring algae in evaporation ponds (Fan et al., 1997). Their goal is to understand the pathways and control points of ecotoxic effects in order to promote or reduce specific algal processes, as appropriate to foodchain accumulation of Se. An additional advantage of keying on the naturally occurring algae is that they are already adapted to the physical-chemical conditions and variations of the SJV evaporation ponds.

Several species of microalgae isolated from San Joaquin Valley evaporation ponds actively transformed selenium oxyanions into volatile alkylselenides, selenonium ions, and proteinaceous selenomethionine (Fan et al., 1997; Fan and Higashi, in press). Although Se volatilization accounted for as high as 70% of the total Se loss from water in laboratory studies (Fan and Higashi, in press), a significant amount of Se was also bioconcentrated in this alga, particularly in proteins where selenomethionine was the dominant form. There was also a major difference in Se allocation into proteins among different algal species (Fan et al., submitted to Analyst); the significance of this is that the different protein-bound selenium content may represent very different foodchain transfer potential among algae. This notion is supported by other studies, e.g. where diet with a higher level of protein led to a higher Se content in fish tissues (Reidel et al., 1997). On the other hand, a higher protein content in water (e.g. from decaying algae) lead to dramatically increased Se volatilization in evaporation pond water by bacteria (Frankenberger and Thompson-Eagle, 1989); but the ecotoxic consequences were not addressed in that study.

At the current time, there appear to be no other algal studies that address ecotoxic bioremediation *per se* in evaporation ponds. The above studies by Fan et al. still have considerable work to be done because the factor(s) that control the ecotoxic foodchain effects of selenium are not sufficiently understood. Consequently, it is not known what practical measurements must be made in order to assess the effectiveness of a process for remediation purposes. This is a classic snarl that has hampered remediation efforts in other fields as well (Cherr and Higashi, 1997). For further views and discussion on this issue, see sections on Wildlife Risk-Based Analysis and Rainbow Ranch Invertebrates in this report as well as In Situ Treatment Technology and Se Biotransformations by Biological Systems in the Treatment Technical Report.

Algal Selenium Removal from Water

Studies on removal of selenium from water - without addressing ecotoxic remediation - have shown interesting results. These are treated briefly here. In 1986, Packer and Knight (1986) reported that the cyanobacteria ("blue-green algae") *Synechoccus* 6311 could be used to remove Se from waters. The mechanism of Se uptake was proposed to be analogous to that of S uptake, and the Se was preferentially taken up over S at low sulfate levels, while the opposite was true at high sulfate levels. The remediation potential of the approach was not discussed. This approach was apparently not pursued, possibly due to the high sulfate content of evaporation ponds.

Over the last decade, a group based at UC-Berkeley has worked on an algal-bacteria system for selenium removal from water (Lundquist et al., 1994). Very briefly stated, the system grows algae to essentially serve as an organic carbon source for bacteria (*Acinetobacter* sp. and *Pseudomonas* sp.) that reduces the selenium oxyanions to forms that can be removed from water (e.g., colloidal Se^0). In its present incarnation (Benson et al., 1997), the focus of the system is on reducing selenium to meet the discharge requirements to rivers, and does not make reference to evaporation ponds *per se*. There is no discussion of the remediation potential of the approach.

Nelson et al. (1997) at UC-Davis developed a laboratory bacterial culture of *Chromatium vinosum* or *Chlorobium limicola* plus *Desulfovibrio desulfuricans* to reduce selenate to selenium-rich intracellular colloids probably containing Se^0. The process is "algal" under our definition because the first two organisms are grown phototrophically under anaerobic conditions, essential for the control of the selenium chemistry. The authors envision the process as useful in a bioreactor situation to remove selenium oxyanions from the water. The remediation potential of the approach was not discussed.

Other Current Work that Includes Algal Processes

In addition to the efforts of algal selenium removal, there are other investigations currently underway that deliberately or incidentally involve algal processes. These are described only briefly here, as they are covered under other topics. Terry (1997) and Tanji et al. (1997) describe a study using a flow-through wetlands for the removal of selenium from water. Because of the open design, including cells which have no vascular plants, the system is intentionally designed to include the effects of algae. As this system has only recently stabilized, there are only preliminary results at this time. For further information, please refer to the section on Flow-through Wetlands.

Parker et al. (1997) are using evaporation pond/wetland mesocosms to track the fate and partitioning of Se. This is intended to be a more defined study of the one described by Terry (1997). Since this is a biogeochemical system, it will involve the action of algae, although there is no intentional inoculation by any species. For further details, please refer to the section on Partial Treatment before Discharge.

Criteria for Success of Selenium Remediation Efforts

As stated above, simple parameters such as waterborne selenium concentration are not likely to be a reliable indicator for efficacy of in situ Se bioremediation technologies. The main reasons for this are reiterated here: 1) The goal of Se remediation is to minimize ecotoxic risk, not just removing Se from waters; 2) Se exposure and toxicity in top predators primarily result from Se biotransformations and transfer pathways through the foodweb, which is not a simple function of waterborne Se concentration. Waterborne selenium concentrations much below 5 µg/L (the current EPA Se freshwater quality criterion) have been shown to have adverse effects on fish (e.g., Lemly, 1993). Conversely, there have been cases where no apparent Se toxicity was observed with waterborne Se concentrations much higher than 5 µg/L (e.g. Canton and Vanderveer, 1997; Hamilton et al., 1997).

Recently, a nine-member expert panel in a "Peer Consultation Workshop on Selenium Aquatic Toxicity and Bioaccumulation" convened by the US Environmental Protection Agency, May 1998, concurred with the above. The purpose of this workshop was to assist EPA in evaluating the scientific literature information relevant to the chronic Se water quality criteria for protecting aquatic community. It was clear from the panel discussion those more reliable parameters such as Se burden in representative tissues and tissue compartments (e.g. proteins) will be needed for Se impact assessment. In the light of these new findings over the last decade, EPA is initiating the process of re-evaluating the current chronic water quality criterion for Se. More reliable parameters, if achieved, will lead to better regulatory criteria for protecting the aquatic community, which is equally crucial for assessing the efficacy of any remediation measure.

VC. Solar Evaporators

Integrated agroforestry systems can be defined as a farming system that reuses tile drainage water on increasingly salt tolerant agronomic crops until the salinity of that drainage is too high for crop production (see Figure VC-1). In order for this system to be sustainable, tile drainage from the last agronomic crop, usually some sort of halophyte, will need to be collected and disposed. In order to optimize the system, the drainage that is collected from the halophytes should be further concentrated so that the salt can be harvested and used is some beneficial way, as noted by the Technical Committee Report on Salt Utilization. If possible, a market for these salts should be found or developed. This is the ideal, and as yet there are still several technical steps that need to be further refined.

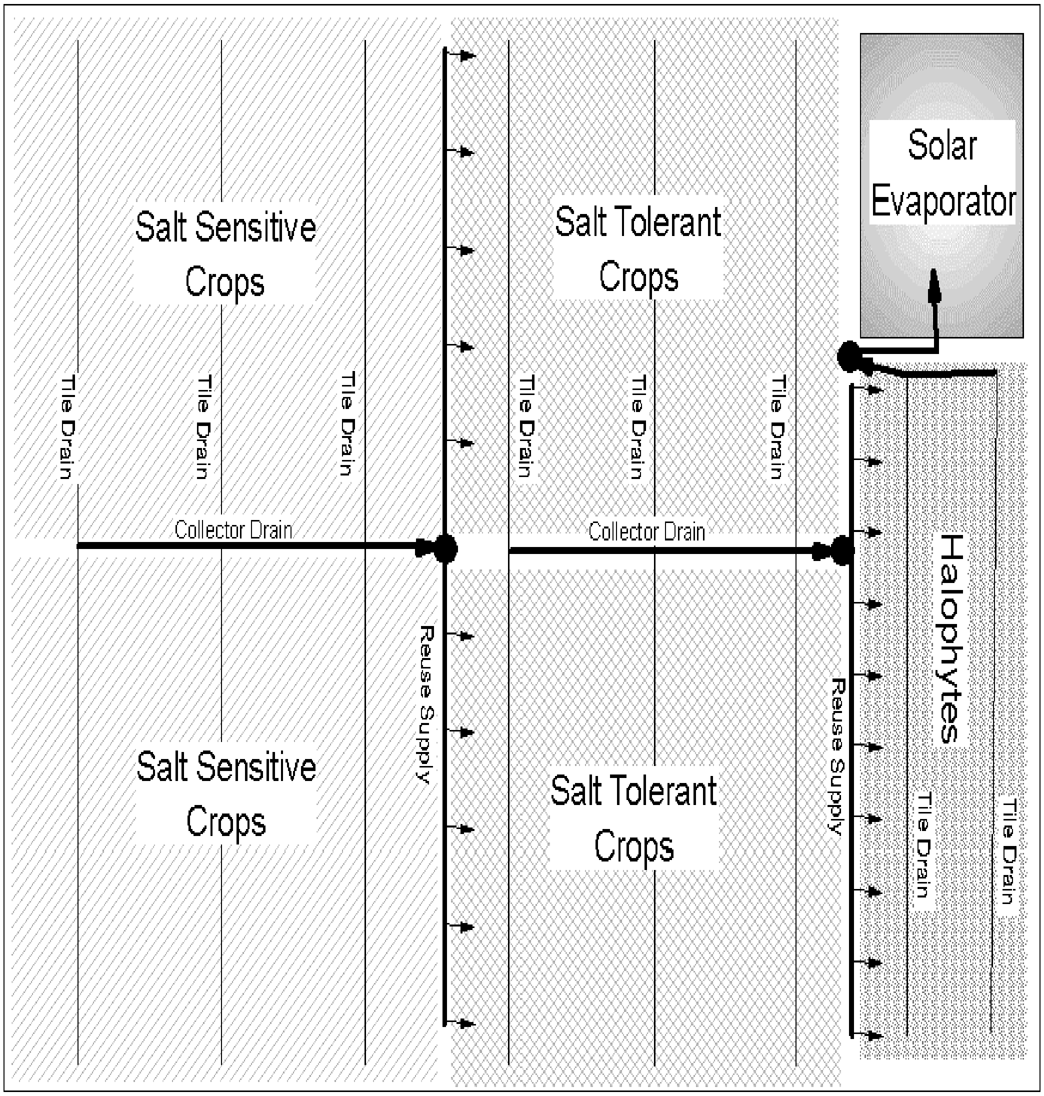
The process that is employed at both the Mendota and Red Rock Ranch reuse demonstration sites to evaporate the concentrated drainage is solar evaporators. A solar evaporator defined herein is similar to an evaporation pond, except that the drainage water is not allowed to pond within the system. In order to do this, the operator must control the flow of the drainage into the solar evaporator so that it matches (or is less than) the rate of evaporation. Two benefits of using solar evaporators are that wildlife impacts should be minimized and salt harvesting is facilitated. A disadvantage is that the solar evaporator has to be sized so that it can operate at a rate that allows for the disposition of all the drainage coming from the agricultural fields within the system. An evaporation pond system, in contrast, stores drain water within the pond. In other words, a pond system only needs to operate at an average rate that matches the average rate of drainage from the agricultural fields while a solar evaporator has to operate at a rate that can handle the maximum rates of discharge from the agricultural fields.

The potential problems associated with solar evaporators mainly concern not being able to operate the evaporators in a way that precludes ponding for more than a day or two. Aquatic invertebrates, the prey base for shorebirds and other wildlife that may be affected by evaporation ponds, can colonize and produce significant populations in saline waters within a week during the summer. These invertebrates are an essential link in the uptake of selenium by shorebirds and other water fowl (DuBowy, 1989; Ohlendorf, 1989; Ohlendorf et al., 1993. Maier and Knight, 1994). The biochemistry of a solar evaporator that has standing water should be very similar to any agricultural drainage evaporation pond. This means that if there were elevated selenium levels within the evaporators, then invertebrates grown in the system would be expected to contain elevated selenium levels and have the potential to adversely affect wildlife. If solar evaporators are used as an "on-farm" solution, their size should be minimized and operation should be simplified. In addition, waterfowl are more easily hazed away from a small system than a large system (Salmon and Marsh, 1991).

VD. Compensation Habitats

As part of the site-specific environmental impact reports prepared in 1993, protocols were presented for calculating unavoidable impacts on American avocet and black-necked stilts, and for calculating a corresponding acreage of compensation wetland habitat required to mitigate for unavoidable losses (Hanson 1993; modified by Hanson 1995). The U.S. Fish and Wildlife Service (1995 a, b) also developed a series of protocols for calculating both compensation habitat requirements to mitigate for
Fig. VC-1

Figure VC-1. Layout of drainwater reuse and solar pond at Red Rock Ranch.



unavoidable losses, and required alternative wetland habitat designed to provide dietary dilution thereby reducing the potential risk of adverse effects. The development of these analytical methods for calculating unavoidable losses was predicated on a variety of assumptions, which could not be verified in the absence of additional monitoring and investigations.

Based upon the preliminary analysis of unavoidable losses waste discharge requirements (WDR's) adopted by the Regional Water Quality Control Board in 1993 for Westlake Farms, Tulare Lake Drainage District's South and Hacienda Evaporation Basins, Lost Hills Water District, and Rainbow Ranch, and other evaporation basins, included preliminary estimates of unavoidable losses and estimates of wetland habitat required to compensate and reduce unavoidable losses to American avocet and black-necked stilts to less-than-significant levels. Subsequent biological monitoring performed at evaporation basins following completion of the modifications, and biological surveys conducted to assess habitat utility and nesting success on wetlands has provided much of the information necessary to refine and verify fundamental assumptions included in the original protocol of compensation habitat requirements.

Various approaches have been proposed for calculating compensation habitat required to mitigate for unavoidable waterbird losses as a result of evaporation basin operations (Hanson 1993; USFWS 1995; Hanson 1995). These compensation habitat protocols are primarily focused on unavoidable adverse effects on American avocet and black-necked stilts. Each of these protocols for calculating compensation habitat utilized data collected through biological monitoring in addition to a variety of assumptions. Data collected during the 1993-1996 period on dietary exposure, waterbird abundance and nesting, and the relative habitat utility and use by waterbirds at evaporation basins, and compensation habitats such as that developed by TLDD, provide empirical information useful in the recalculation of compensation habitat requirements. Scientific data collected in recent years has been used to refine and validate many of the basic assumptions incorporated in these protocols, such as the level of effectiveness of structural and operational modifications to evaporation basins in reducing nesting activity by species such as stilts and avocets, and the performance of managed compensation wetland habitat for nesting waterbirds. Using data from the more recent biological surveys, estimates of the compensation habitat required to mitigate for unavoidable losses associated with the

TLDD South and Hacienda Evaporation Basins have been calculated using the different protocols (Hanson 1993; USFWS 1995; Hanson 1995) and are summarized for comparative purposes below:

Original 1993-1995 Compensation	Compensation
Habitat estimates for TLDD	Habitat Acreage
1993 TLDD EIR	207
1995 USFWS Egg-wise	318
1995 USFWS Hen-wise	315
Revised Compensation Habitat Estimates for TLDD using 1995-1996 Scientific Data	
1993 EIR Protocol and 1995-96 survey data	36
1995 USFWS Egg-wise Protocol and 1995-96 survey data	12
1995 USFWS Hen-wise Protocol and 1995-96 survey data	12
1995 Hanson Revised Protocol and 1995-96 survey data	17

As shown above, the compensation habitat requirements (acres) calculated using each of the protocols have converged to provide very similar estimates of compensation habitat requirements. Furthermore, the estimated wetland acreage required for compensation habitat has declined substantially from earlier estimates, largely based upon refinements to the protocols and the underlying scientific assumptions as modified using monitoring data collected in recent years. Further examination of compensation habitat requirements and the performance of each of the protocols will continue as part of the ongoing performance review and Waste Discharge Requirements (WDR) compliance monitoring program. Information on the level of nesting activity and performance of managed compensation wetland habitats, particularly under drought conditions, will be important to consider as part of future evaluations of evaporation basin operations and the performance of compensation habitat to mitigate for unavoidable impacts.

The reduction in compensation habitat requirements reflects, in part, (1) the observed reductions in American avocet and black-necked stilt nesting at the evaporation basins following completion of the modifications to their design and operations and (2) high habitat use and nesting success for American avocet and black-necked stilts at wetland habitat specifically designed and managed to provide foraging and nesting habitat. Continued monitoring will be required over a period of years representing a variety of environmental conditions to fully evaluate and verify the performance of wetland habitat designed to mitigate and compensate for unavoidable losses.

Alternative Habitat

The U.S. Fish and Wildlife Service has proposed the construction and operation of year-round freshwater habitat immediately adjacent to evaporation basins for the purpose of providing an alternative wetland habitat to improve the effectiveness of evaporation basin hazing and contribute to dietary dilution of selenium exposure. Alternative habitat is generally recommended to be located within a distance of 3 km of the evaporation basin assuming that suitable lands and water supply facilities are available. The U.S. Fish and Wildlife Service developed a proposed protocol for calculating alternative habitat acreage (USFWS 1995). The alternative habitat protocol is based on consideration of a dilution standard (proposed to be 2.6 ppm dietary selenium), evaporation basin dietary exposure calculated using the geometric mean concentration of selenium in stilt and avocet eggs, the alternative habitat dietary exposure, the proportion of dietary exposure to selenium originating at the evaporation basin and that originating at the alternative habitat, the size (acres) of the evaporation basin, and an estimate of the relative attractiveness of the alternative habitat. The alternative habitat protocol was developed based upon data collected for American avocet and black-necked stilts.

A number of San Joaquin Valley evaporation basin operators entered into agreements with USFWS which stipulated that alternative habitat would be implemented as part of an overall mitigation program required for continued evaporation basin operations. After entering into these agreements a number of these evaporation basin operators decided to discontinue agricultural drainage and evaporation basin operations, in part in response to costs associated with alternative habitat construction and operation and environmental compliance. Since evaporation basins at these facilities were removed from service, alternative habitats were not constructed by these operators. Westlake Farms, Lost Hills Water District, and Rainbow Ranch have implemented, or are currently evaluating the feasibility of implementing, alternative habitat. The Tulare Lake Drainage District did not enter into agreements with USFWS and has not constructed alternative wetland habitat adjacent to either the South or Hacienda Evaporation Basins.

Alternative habitat was considered as one of the potential elements of a set of management actions for the TLDD South and Hacienda Evaporation Basins as part of the 1993 Environmental Impact Report prepared for the Central Valley Regional Water Quality Control Board. The effectiveness of alternative habitat had not, however, been tested or evaluated, particularly in combination with other management actions being considered for application at the TLDD evaporation basins. Based upon the analyses performed in 1993, a series of management actions was identified for implementation at the South and Hacienda Evaporation Basins which included increasing levee slopes, removal of windbreak islands, increased hazing, cell water depth management, vegetation control, and construction of a compensation wetland habitat. Alternative habitat was not included as part of the recommended set of actions. Biological monitoring at the South and Hacienda Evaporation Basins was initiated to provide the necessary scientific information to evaluate the effectiveness of these actions in reducing waterbird usage and nesting, and to provide additional scientific information for future evaluations of the potential application of alternative habitat. The Regional Water Quality Control Board certified the proposed management plan included in the 1993 EIR, and did not require that TLDD construct alternative habitat.

Results of monitoring conducted at the South and Hacienda Evaporation Basins since 1993 have been documented in a number of technical reports prepared by TLDD in compliance with requirements of the WDR, and for use in evaluating performance of the existing actions in avoiding and minimizing adverse impacts. Monitoring is also being performed at other evaporation basins (e.g., Westlake Farms, Lost Hills Water District), in addition to monitoring within seasonally flooded areas, to provide information regarding the effectiveness and performance of alternative habitat.

The construction and operation of alternative habitat is expensive, particularly as a result of high costs associated with a reliable freshwater source. For example, the preliminary annualized cost derived for evaluating alternative habitat costs associated with the TLDD South and Hacienda Evaporation Basin operations was estimated to be $1,557.00 per acre per year (Northwest Economics Associates, 1997). This estimated cost is based on an assumed water cost of $100.00 per acre-foot. Since under the USFWS protocol alternative habitat would need to be maintained in all years, the cost of a reliable water supply source during years of low water supplies (drought conditions) is expected to be substantially higher (e.g., $200.00 per acre foot or more). Based upon the annualized cost of $1,557.00 per acre, the estimated cost of alternative habitat is shown in the example below:

Alternative Habitat Acreage	Estimated Annual Cost
100	$155,700
500	$778,500
1,000	$1,557,000
2,000	$3,114,000

The magnitude of alternative habitat requirements calculated using the USFWS (1995) protocol results in alternative habitat estimates exceeding 2,000 acres for both the Lost Hills Water District and Tulare Lake Drainage District. Data collected in recent years regarding selenium dietary exposure and the performance of managed wetlands have contributed to a general decline in the estimated alternative habitat requirements. However, additional monitoring and evaluation of the performance and biological benefits of alternative habitat at wetland areas such as those developed by Westlake

Farms is needed. Additional information is also needed to refine the costs associated with construction and operations of alternative habitat, in combination with costs of other environmental monitoring and mitigation activities. The cost of these environmental activities will result in a direct increase in the fees to farmers for agricultural drainage operation. The economic impact of these increased costs on the net return on investment for farming operations also needs to be evaluated.

Consideration is also being given to the potential opportunities for developing alternative habitat on a seasonal basis when freshwater supplies are available from surplus flows and flooding, which would not be sustained year-round or in those years when surplus water supplies are not available. Additional information is also being collected on the effect of basic design, operations, and maintenance practices of alternative wetland habitat on the attractiveness for wildlife use and the overall biological benefits associated with alternative habitat implementation. These evaluations and data collection activities are currently underway and will provide improved information in future years for assessing and evaluating the incremental benefits of alternative habitat, in addition to other modifications which have been made to evaporation basin facilities and their operation.

The design and performance of compensation wetland habitats associated with evaporation basin operations since 1993 are briefly described below.

Tulare Lake Drainage District (TLDD)

The development of wetland habitat within the San Joaquin Valley to mitigate for adverse effects on waterbirds, particularly species such as black-necked stilt and American avocet, has been constrained by the availability of a reliable water supply source. Many of the waterbird species of interest inhabit coastal marine areas. Macroinvertebrates, which provide the forage base for many of these species, also occur in relatively high abundance in saline waters. Based on these and other considerations, saline agricultural drainage water, having low selenium concentrations, has been identified and used as a water supply source for wetland habitat. Saline drainwater has been used as a supplemental water supply source for the TLDD Compensation Wetland Habitat over the past several years. The TLDD Compensation Wetland Habitat was designed to be operated using freshwater supplies, saline agricultural drainage water having low concentrations of selenium, or a blend of freshwater and saline waters. Detailed monitoring of electrical conductivity and selenium concentrations has been used to manage saline drainwater and to blend saline drainwater with freshwater within wetland habitats.

The use of saline agricultural drainage water having low concentrations of selenium as a supplemental water supply for blending and use within the TLDD Compensation Wetland Habitat is consistent with California water policy regarding the efficient use and re-use of available supplies. Recycling agricultural drainage water that meets specific water quality criteria for protection of wildlife, for use as a supplemental supply at the Compensation Wetland Habitat is consistent with the policies of the Central

Valley Regional Water Quality Control Board. The U.S. Fish and Wildlife Service (USFWS) and other agencies have expressed concern, however, regarding the use of low-selenium saline drainage water and the potential for adverse effects other than selenium, when used to support wetlands. Specific water quality criteria for constituents other than selenium, applicable to the water supplies used in wetland habitats have not been established.

Monitoring of water quality constituents within wetland habitats supplied by saline drainwater such as the TLDD Compensation Habitat, in combination with continued biological monitoring over the next several years, will provide useful information to further evaluate and document the applicability of the use of saline drainwater as a wetland water supply source. The use of saline drainwater within the TLDD Compensation Wetland Habitat is subject to regulation by the Central Valley Regional Water Quality Control Board. The data collected as part of the ongoing TLDD Compensation Habitat Water Quality and Biological Monitoring Program will provide scientific and technical information useful to the Regional Board in establishing future regulatory conditions for the use of drainage water as a supply for wetland habitat.

The use of saline drainwater within seasonal wetland habitat used as foraging and nesting areas by American avocet and black-necked stilts at the TLDD Compensation Habitat has, to date, provided promising results. Saline waters within the habitat support high densities of macroinvertebrates. High densities of nesting stilts and avocets have also been documented.

The TLDD Compensation Habitat, approximately 307 acres in size, was designed specifically to provide foraging and nesting habitat for American avocets and black-necked stilts. The Compensation Habitat includes low-profile islands immediately adjacent to extensive shallow-water areas (12:1 levee slopes) which support macroinvertebrate production and provide extensive foraging and nesting. The habitat is operated to maintain a water depth of four to six inches - the preferred foraging water depth for shorebirds. The habitat is operated as a flow-through system, thereby reducing the potential impact of evaporation on water quality. Experience in operating the Compensation Habitat over the past several years has demonstrated the importance of routine annual vegetation control in maintaining acceptable nesting habitat for American avocet and black-necked stilts within the wetland. The Compensation Habitat is completely surrounded by an electrified predator-exclusion fence. The primary predator of concern in the area is the coyote, although raccoon, opossum, skunk, and badger are also known predators in the area.

The TLDD Compensation Habitat is operated from late February to August, coinciding with the nesting period for avocets and stilts. The Compensation Habitat began operations during the 1995-breeding season. Biological monitoring is performed at the Compensation Habitat each year to assess bird use, nesting, and reproductive success. Results of waterbird nest monitoring at the TLDD compensation wetland habitat (Mayfield adjusted) are summarized below for American avocet and black-necked stilt:

Year	Stilt and Avocet nesting, TLDD Compensation Wetland
1995	2165
1996	1771
1997	3372
1998	3968[1]

No embryonic deformities were detected in American avocet or black-necked stilt eggs collected in 1995 -1998 at the Compensation Habitat.

Results of nest monitoring for American avocet and black-necked stilts at the TLDD South and Hacienda Evaporation Basins and at the compensation wetland (Mayfield adjusted) are compared in Figure VD-1. Results of these comparisons, to date, are consistent with the goals and objectives identified in the 1993 TLDD site-specific environmental impact report (Hanson 1993), and provisions of the WDR in (1) substantially reducing the numbers of stilts and avocets foraging and nesting at the TLDD South and Hacienda Evaporation Basins thereby reducing exposure to selenium and other water quality constituents and the risk of adverse impacts resulting from evaporation basin operations; and (2) mitigate for unavoidable waterbird losses by providing compensation wetland habitat which provides nesting and foraging habitat at a sufficient level to reduce adverse impacts associated with evaporation basin operations to less than significant levels. Additional monitoring at both the evaporation basins and compensation habitat will be required, particularly during dry year conditions when naturally occurring flood waters create temporary wetland habitat.

Westlake Farms, Inc.

During fall 1993, Westlake Farms constructed a 145-acre alternative wetland adjacent to the south evaporation basin. The site consists of six cells. Each cell has a series of large and small nesting and loafing islands. During fall 1994 the islands in one cell were modified and drainage channels and additional islands were added. A new anti-predator borrow ditch was constructed during fall 1995. In 1995 Westlake Farms modified the water-input system such that each cell had an independent inlet pipe. This system provided stable water depths and efficient fresh water circulation through each cell.

During 1993, Westlake Farms provided approximately 640 acres of wetland habitat. Westlake Farms constructed islands the following winter and flooded these cells for the 1994-breeding season. These cells initiated the Wetland Demonstration Project, a cooperative effort, between Westlake Farms, the U.S. Fish and Wildlife Service, the U. S. Bureau of Reclamation, the California Department of Water Resources, and the California Department of Fish and Game. During fall 1995 and winter 1996, Westlake Farms modified the wetland by adding a contour dike splitting two large cells into four smaller ponds. Large and small islands were constructed for the 1996-breeding season.

Westlake Farms provided water to Section 16 from February to August 1996. During 1996, a barley/vetch mixture was planted for upland nesting species such as pheasants and waterfowl. Westlake Farms flooded approximately 640 acres in Section 23 from January to August 1995. Westlake Farms provided water to Section 23 from February to August 1996. This site also provided compensation habitat for LHWD in 1995 and 1996.

Overall, avian densities at the alternative wetland were significantly higher than the evaporation basin, which indicates that the alternative wetland was highly attractive to birds. Nest success at the alternative wetland (77%) and at the Wetland Demonstration

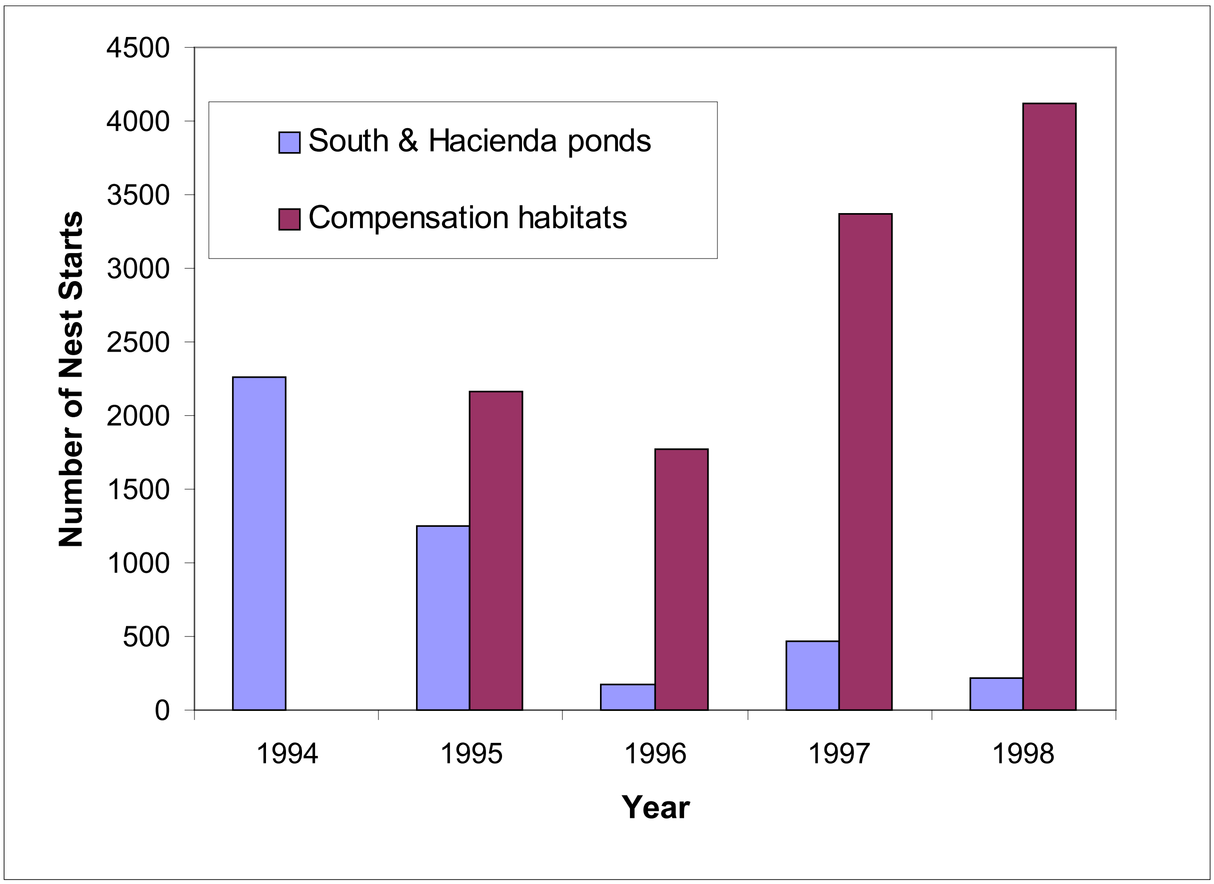


Figure VD-1. Comparison of Mayfield adjusted nest estimates for American avocet and Black-necked stilts at the TLDD South and Hacienda Evaporation Basins and Compensation Habitat.

Project (51%) was relatively high during the first year of operation. Coyote predation, most of which occurred on the contour border dikes, was the main cause of nest failure at the Wetland Demonstration Project. Raccoons were the primary predators on the islands and the coyote was the primary predator on the border dikes at the alternative wetland.

In 1995, the number of nest attempts at the alternative wetland declined from the previous year. The decline was most likely due to high predation and predator harassment. To decrease coyote predation, Westlake Farms installed fences across the border dikes and began a predator control program. The deep anti-predator borrow ditch that surrounds the alternative wetland appeared to discourage coyotes from attempting to swim to the islands. After the fences were installed on the border dikes coyotes activity appeared to decrease, but raccoons continued to swim around the fence and travel down the dikes. Therefore, raccoon predation continued to be a problem, as was avian predation.

The mitigation wetlands supported 2,946 observed nest attempts, while both evaporation basins supported 744 nest attempts from 1994 to 1996. However, themitigation and demonstration sites supported substantially higher numbers of nests than reported, because Sections 16 and 23 were not completely surveyed each year.

Britz, Inc.

In accordance with the WDR's for the operation of the evaporation basin, Britz, Inc. Provided enough water to enhance approximately 25 acres of wetland habitat during the 1995 breeding seasons. In 1996, in accordance with the USFWS Settlement Agreement, Britz, Inc., provided three acres of compensation wetland habitat and 15 acres of demonstration habitat at Gragnani Farms. In 1992, the Soil Conservation Service (SCS) purchased the easement rights on Gragnani Farms as part of the federal Wetland Reserve Program to control and store floodwaters on former or existing wetlands. The SCS, now NRCS, and Gragnani Farms have been in the process of re-establishing wetland and upland habitats.

During 1995, Britz, Inc., constructed an eight-acre alternative wetland, one mile east of the evaporation basin. This pond was built in accordance to the USFWS Settlement Agreement. This site has two large nesting islands and a deep anti-predator ditch surrounding the pond. The pond was flooded from March 15 to October 15, 1996.

Total nesting attempts at the compensation wetland were 15 and 18 in 1995 and 1996, respectively. From 1995 to 1996, most (82%) of the nests hatched chicks and 15% (5 nests) were destroyed by a predator. Black-necked Stilts, American Avocets, and Killdeer were the primary breeders at the compensation wetland. Egg selenium concentrations at Gragnani Farms were below background levels at both mitigation wetlands.

Lost Hills Water District (LHWD)

The 1993 WDR stated that LHWD would provide 1,500 ac-ft of water to Kern NWR as compensation habitat for waterbirds. Based on the 1995 USFWS alternative and compensation habitat protocol, LHWD should provide 2,389 acres of alternative wetland and 113 acres of compensation habitat as mitigation. The USFWS protocol re-evaluation, based on updated egg selenium results (1994 to 1997) and evaporation basin acreage, suggests LHWD should provide 56 to 498 acres of alternative wetlands and 38 acres of compensation wetland. The Hanson (1995) compensation mitigation protocol suggests 5 to 32 acres.

Lost Hills Water District has implemented compensation and/or alternative wetland habitat through several different methods including providing water supplies to support the compensation wetlands at Westlake Farms, development of alternative wetlands, providing wintering wetlands, providing water supplies to the Kern National Wildlife Refuge, providing water supplies to support wetlands at local duck clubs, in combination with other activities within the District's service area such as pre-irrigation, water supply storage, conveyance canals, and other areas that provide direct or indirect habitat benefits for wildlife. The major activities provided by LHWD in support of compensation and/or alternative wetland habitat are briefly summarized below.

Compensation Wetlands at Westlake Farms

Westlake Farms, Inc. is located in the southwest San Joaquin Valley approximately 26 miles northwest of the LHWD evaporation basin. Westlake Farms, Inc., flooded Section 23 to store floodwaters for crop irrigation. Section 23 has 16 wetland cells. Biologists monitored nest success at this site, which comprised 420 acres (1995) and 465 acres (1996) of wetland habitat. In late-April 1997, five large nesting islands were added to the wetland before flooding. In 1997, 270 acres were flooded. The remaining cells were kept dry as a means to dry out dense cattail stands for later burning.

Experimental Alternative Wetlands

From April through July 1997, LHWD provided approximately 120 acres of flooded area to experiment with water management and monitor bird use and nest success at a site within three miles from the evaporation basin. This site is approximately 3 miles east of the evaporation basin and 0.5 mile west of Kern National Wildlife Refuge.

Mitigation Wintering Wetlands

Lost Hills Water District provided water to four abandoned duck club ponds south of Kern National Wildlife Refuge during the late-fall to early winter in 1993/94 and 1994/95. Lost Hills Water District also provided water to a site in the Goose Lake Basin during the fall 1995. Without LHWD water these five sites would have remained dry.

Wetlands at Kern National Wildlife Refuge (NWR)

From May to June 1994, LHWD provided 600 ac-ft of water to Kern NWR (Unit I) as a means of providing clean water for waterbirds near the LHWD evaporation basin.

Wetlands at Adelaida Duck Club

Lost Hills Water District provided 400 ac-ft of water to a 160-acre pond at the Adelaida Duck Club from April to June 1995. Adelaida Duck Club has an abandoned pond that was dry for a number of years. Without LHWD water, this pond would have remained dry.

Lost Hills Water District has proposed to develop a compensation wetland that will be functional from March 1 to August 1. Water levels will be maintained from 3 to 8 inches (mean depths will be approximately 6 inches). Water will flow through the system (or cells) on a continuous basis to prevent stagnation, which will decrease the likelihood of an avian botulism outbreak during hot summer months. Emergent vegetation will not cover more that 30% of the ponds (70% open water areas). Cattail control (discing) will occur every 4 to 5 years or sooner if needed. Islands and levees will be maintained (i.e. for erosion damage) and will be treated (fire or discing) to remove most vegetation, which will provide open nesting areas for recurvirostrids. Water will be drawn down on August 1, which will provide shallow water and mudflats for fall migrants (i.e. sandpipers, dowitchers). The drawdown, drying and aeration of the soil will provide conditions that will enhance submergent vegetation and aquatic invertebrate production after the ponds are reflooded the following spring. All maintenance activities will occur in the fall to early winter months before the winter rains appear.

Lost Hills Water District also proposes to provide approximately 100 acres of alternative wetlands that will be flooded on a continuous basis while the evaporation basin is in operation. The site is located adjacent to the Kern River channel. This location is unique, in that the Kern River Channel serves as a wildlife corridor between the Tulare Lake and Goose Lake Basins. This site is one mile west of the Kern NWR western boundary.

Rainbow Ranch

In 1994, Rainbow Ranch surveyed and engineered a site to develop approximately 105 acres of freshwater wetland adjacent to the existing evaporation basin. After initially endorsing the plan, the U.S. Fish and Wildlife Service and California Department of Fish and Game expressed concerns about the close proximity (within three miles) of the wetland to the evaporation basin. Agency personnel suggested Rainbow Ranch provide water for habitat at a more remote location (between 3 and 20 miles away from the evaporation basin) for an interim period of three years.

The USFWS protocol suggested Rainbow Ranch provide 33 acres of alternative habitat and 21 acres of compensatory habitat. The USFWS revised the protocols and proposed that Rainbow Ranch provide 89 acres of alternative habitat near the existing evaporation basin and 21 acres of compensatory habitat more than 5 kilometers (3 miles) away from the basin. The 21-acre compensatory habitat could be consolidated with compensatory habitat of other evaporation pond operators to form one or two large shorebird breeding sites in the valley.

The USFWS supported Rainbow Ranch's proposal to provide 50 acres of alternative habitat approximately 1.25 miles southwest of the existing evaporation basin. The Chevron Corporation owns this site. Rainbow Ranch also proposed to provide water for 50 acres of compensatory habitat in Section 16 at Westlake Farms. The Chevron site provided additional information about the effects of providing an alternative wetland between 1 and 5 kilometers from an evaporation basin.

From March 1995 to 1997, Rainbow Ranch provided 50 acres of alternative habitat at the "Chevron site". The 50-acre site is divided into four triangular shaped cells. Rainbow Ranch removed dense vegetation from the dike banks, which provided open feeding and resting areas for shorebirds and waterfowl. During 1996, Rainbow Ranch constructed nesting islands and contour levees within the wetland. Rainbow Ranch also chopped and disced the cattail stands to provide open water feeding areas for shorebirds.

In 1995, Rainbow Ranch finalized a 3-year Memorandum of Understanding to provide 50 acres of compensatory habitat from April 1 to August 1 in Section 16 at Westlake Farms

Bird use at the alternative wetland was relatively high during 1995 and 1996. The primary species groups that used the wetland on a continuous basis included dabbling ducks, American Coots, and recurvirostrids, whereas shorebird use varied among seasons. Eared Grebes, diving ducks, and other species (i.e. gulls, terns, waders, etc.) did not appear to use the site in high numbers or on a regular basis.

Nesting activity at the alternative wetland declined in 1996 compared to 1995, more than likely due to the invasion of cattails. Overall nest success was relatively high for both years. In 1997, Rainbow Ranch discontinued pumping water into the Chevron site because of concerns that seepage from the wetland was damaging a neighbor's property. This made it difficult to maintain the site as planned for recurvirostrid nesting habitat. The Chevron site provided habitat for other waterbirds species such as waterfowl and coots.

Accurate censusing of birds at the compensation wetland was difficult due to widespread emergent vegetation (cattails) which impeded visibility across the ponds. However, the cattail stands provided "habitat diversity", which in turn attracted a diversity of bird species to the site.

During the 1995-breeding season, Rainbow Ranch compensation wetland supported up to 200 recurvirostrids. Bird use increased during the water drawdown, which increased exposed mudflats, and coincided with the early fall migration. During spring 1996, Rainbow Ranch compensation wetland had approximately 75 recurvirostrids present. However, as the cattail stands began to increase, recurvirostrid numbers decreased, due to reduced areas of open water and reduced visibility, which made it more difficult to detect birds during censusing. The compensation wetland attracted a wide diversity of bird species compared to the evaporation basin. In 1997, the site was attractive to cattail dependent species such as the American Bittern, White-faced Ibis, rails, blackbirds, Great-tailed Grackles (*Quiscalus mexicanus*), and herons. Vegetation on the islands and dikes was too dense to attract nesting shorebirds. The open water areas, or potholes, provided feeding and brooding areas for a variety of waterbirds.

Incidental Wildlife Use on Agricultural Lands

In addition to the constructed compensation and alternative habitats, wildlife incidentally utilizes agricultural lands. Some of the committee members believe incidental use of agricultural lands by waterbirds is an inappropriate topic under this section. Such incidental use might offer some benefits, but some uses may be fraught with risks to wildlife (e.g., duck nests in grain fields are commonly destroyed during harvest and waterbird nests in water storage areas are commonly destroyed or abandoned when water levels are rapidly raised or lowered depending on irrigation or storage demands). The net balance of benefit and risk is unknown and bears no definable compensatory relationship to adverse impacts of evaporation ponds. Nevertheless, the committee chair has included this topic because there appears to be some benefits such as bird usage of impounded waters during solarization.

Land use within the San Joaquin Valley includes extensive irrigated agricultural lands, an extensive network of water supply canals and storage facilities, managed and unmanaged wildlife habitat, urbanized areas, and other land uses in addition to agricultural drainage water evaporation basins. Seasonal floodwater storage areas, which provide water storage for agricultural irrigation, are also present. During the non-breeding season (roughly September through March), extensive acreage of agricultural lands are flooded at various depths and for varying durations as part of both pre-irrigation and solarization activities. Solarization, a treatment for soil fungus, involves covering a field with deep water (12 inches or more) for up to 30 days at a time. Pre-irrigation involves a quick wetting of a field in which standing water is usually present for only approximately 48 hours at a depth usually less than 6 inches. Waterbirds and other wildlife have been observed utilizing these seasonally flooded agricultural lands, flood storage areas, and agricultural irrigation water supply and delivery canals.

Surveys have been performed on the numbers and species of birds present on agricultural fields during pre-irrigation and solarization activities. Surveys were performed to characterize bird use of flooded agricultural lands during the winter (October 1995-February 1996) and fall (September 1996: R. Hansen, unpublished data; TLDD 1997). These surveys included over 30,000 acres flooded by solarization and 14,000 acres flooded by pre-irrigation techniques. A total of approximately 188,000 birds were observed on agricultural lands flooded by solarization representing an average density of 6.2 birds per flooded acre. Approximately 15,500 birds were observed on agricultural lands flooded during pre-irrigation representing an average density of approximately 1.1 birds per flooded acre. These non-breeding birds were observed to be loafing and foraging. Results of these surveys clearly show extensive use of seasonally flooded agricultural lands by a variety of birds. Results of these surveys do not, however, provide the data necessary to actually evaluate the biological benefits to non-breeding bird populations resulting from the availability of seasonally flooded agricultural lands.

Qualitative surveys have also demonstrated the use of agricultural irrigation water supply canals by a variety of waterbirds including, but not limited to, ducks and other waterfowl, heron, and egrets. Many of the water supply canals are inhabited by various aquatic vegetation, macroinvertebrates, and fish, which provide a forage base for various bird species. Quantitative surveys have not been conducted, however, to document the abundance, nesting activity, or potential biological benefits to these bird species resulting from operation of irrigation canals and water supply distribution systems.

Extensive areas of the San Joaquin Valley such as those within the Tulare Lake Basin are subject to periodic flooding during years of high precipitation and run-off. For example, in 1995 a total of 20,700 acres within the South Wilbur/Hacienda complex were used for water storage and floodwater management. During 1996 approximately 12,000 acres were flooded for water storage and floodwater management. Observations conducted within these areas have shown that a variety of waterbird species are present with many of the birds observed to be actively foraging and nesting within the area. Nesting success of a number of the birds was adversely affected by nest flooding resulting from fluctuating water levels within the flood control areas. Investigations have not been performed, however, to document and evaluate the overall benefits and impacts associated with floodwater storage activities on waterbird populations inhabiting the San Joaquin Valley.

Summary

Results of site-specific environmental analyses showed that at some evaporation basins, characterized by low selenium concentrations, no modifications to the design or operation of the facilities was required, and no losses occurred therefore no compensation for unavoidable losses was necessary. At other facilities, such as those operated by TLDD, Westlake Farms, Britz, LHWD, and Rainbow Ranch modifications to evaporation basins and/or compensation for unavoidable losses has been identified. Protocols have been developed (Hanson 1993, 1995; USFWS 1995a,b) for calculating compensation habitat required to mitigate for unavoidable impacts of evaporation basin operations on stilts and avocets. These protocols utilize site-specific information on waterborne selenium concentrations, abundance of nesting stilts and avocets at the evaporation basin, and the anticipated density (number per acre) of stilts and avocets at a managed wetland site, in addition to other information when calculating compensation habitat to mitigate for unavoidable losses as a result of evaporation basin operations. The site-specific approach to evaluating compensation habitat has resulted in requirements for some evaporation basins, such as the TLDD South and Hacienda Evaporation Basins, in compensation requirements substantially less than the 1:1 evaporation basin: compensation habitat presented in the 1990 report.

The site-specific analysis of compensation habitat requirements and the assessment of potential impacts has shown that for some basins, such as those operated by Stone Land Company and C. Meyers, where waterborne selenium concentrations are low and the risk of potential adverse effects on waterbirds is minimal, no compensation or alternative wetland habitat is required. Results of site-specific impact analysis and mitigation requirements may also result in compensation and/or alternative wetland habitat requirements, which may differ from the 1:1 ratio presented in the 1990 report.

The application of site-specific environmental analyses and the associated site-specific calculations of compensation and/or alternative wetland habitat utilizing current protocols represent a substantial change from the 1:1 mitigation approach presented in the 1990 report.

Results of biological monitoring conducted since 1993 has shown substantial reductions in the numbers of waterbirds, particularly American avocet and black-necked stilts, nesting at evaporation basins after modifications have been implemented and that the numbers of stilts and avocets successfully nesting at compensation habitats is substantially higher than originally expected. Scientific investigations are continuing to provide additional information regarding the potential benefits associated with alternative wetland habitat, the use of low-selenium saline water supplies for wetland habitat, and other scientific investigations and monitoring activities. Monitoring of waterbird nesting, abundance, nest fate, egg selenium, and embryonic conditions within operating evaporation basins and compensation and/or alternative habitat will continue in compliance with requirements of the WDR's.

Information developed since 1993 regarding compensation habitat has shown:

1. Compensation wetland habitat can be designed and operated successfully which support high densities of nesting waterbirds;

2. Nesting success has been shown to be high at several compensation habitats where predator exclusion has been effective;

3. A carefully designed vegetation control program can contribute to the long-term success of the mitigation site;

4. Relatively large numbers of young waterbirds are produced at compensation wetland habitats when compared to current estimates of waterbird nesting at several of the evaporation basins managed in accordance with the WDR's, however, the contribution of production from these areas to the adult population and the net environmental benefits of compensation habitats have not been quantified. Results of biological monitoring at compensation wetland habitats conducted to date, has been promising;

5. Various protocols used to estimate compensation habitat requirements have been refined using biological data collected since 1993 and produce very similar estimates of habitat requirements based on site-specific information regarding evaporation basin characteristics;

6. A scientific site-specific calculation of compensation habitat requirements has been developed and is being tested in the Tulare Lake Basin. This site-specific approach resulted in lower estimates of compensation habitat requirement compared to the 1:1 pond: habitat ratio recommended in the 1990 plan.

Monitoring is continuing to refine the performance of compensation habitats and to address questions concerning issues such as the use of saline water supplies having low-selenium concentrations as a water supply to wetlands, performance under drought conditions, alternative wetland design and operations, and the relationship between waterbird production on compensation wetlands relative to the mitigation requirements to reduce unavoidable evaporation basin impacts to less-than-significant levels, and the contribution of compensation habitat production to the adult waterbird population and the associated assessment of net environmental benefits.

VE. Rainbow Ranch Pond Invertebrates

During the shorebird breeding seasons from 1994-96, lower than expected values of selenium were found in eggs collected at the Rainbow Ranch evaporation pond. According to the Rainbow Ranch Mitigation Assessment and Technical Report (H.T. Harvey & Associates, 1997), the mean expected value of selenium during the three-year study in avian eggs was 38 ppm dry weight. However, the observed value was 12 ppm dry weight (n=13) with a concentration range of 2.1-19 ppm dry weight. All eggs, except for one, were found to have values in the range to observe a decrease in hatchability (> 8 ppm) and increase in teratogenesis (>13-24 ppm).

In August 1997, the California Department of Water Resources entered into an agreement with Rainbow Ranch Inc. to study the conditions that exist at the Rainbow Ranch Evaporation Basin and the ongoing operation of this basin. This study will try to identify the factor or factors that resulted in lower than expected selenium levels in shorebird body tissue and eggs.

Although other factors may be responsible or contribute, the most likely factor affecting the biomagnification at Rainbow Ranch is partitioning and isolation of the highest selenium water from the biota. Theoretically, if an evaporation pond cell becomes stratified as in Figure VE-1, and the hypolimnion becomes more saline and hot, it is reasonable to assume that aquatic invertebrates would be inhibited from freely moving between strata. If confined, the aquatic invertebrates could be isolated from the strata that contains the highest selenium concentrations or from the area where it is easiest to pick up selenium.

The Rainbow Ranch ponds have been operated over the past few years in an effort to maintain maximum salinity levels as low as possible (Don Turndrup, personal communication). In order to accomplish this, the inlet into the pond system is rerouted to a cell whenever that cell's salinity rises higher than the others. Since the inlet water (drainage that has not undergone evapoconcentration yet) is fresher than that already in the cells, the salinity of the highly saline cells can be modified. This type of operation may also produce a salinity gradient within the cell by floating less dense inlet water over the top of the denser, highly saline pond water (see Figure VE -2).

A salinity gradient is difficult to transverse for many small organisms due to the change in physiological conditions. If an aquatic organism's physiological systems are capable of withstanding the osmotic pressures at a certain level of salinity, it is difficult to switch its physiology to a salinity level that may be levels of magnitude different.

In addition to osmotic potential difficulties, temperature differences can also be inhibiting the ability of an aquatic organism to traverse the various strata. This temperature difference can be established if the epiliminion is relatively transparent and shallow, and solar radiation can super-heat the hypolimnion to a point where multi-celled organisms are inhibited (Figure VE-3). Similar to problems of traversing salinity gradients, temperature gradients are difficult for an organism to transverse.

For the biomagnification of selenium through the food chain, invertebrate access to the sediment or sediment/water interface is important.

VF. Commercial Harvesting of Artemia Brine Shrimp in Evaporation Ponds

Since October 1997, Novalek, Inc., of Hayward, California, has been developing procedures for the commercial harvest of Artemia Brine Shrimp (anostracan branchiopod crustaceans) from the evaporation ponds in Kern and Kings Counties, California.

Novalek is a research and development company with a history since 1950 through its predecessor companies of commercially harvesting brine shrimp in Asia, Oceania and North America. Its market for premium brine shrimp and other high quality aquatic products is world wide in aquaculture and the aquarium trades. In recent years Novalek has been active in commercially harvesting brine shrimp in San Francisco Bay, California, and Great Salt Lake, Utah. The original company, established before Novalek, was formed by aquatic biologists on the staff of the Steinhart Aquarium, under the administration of the governing California Academy of Sciences, San Francisco. Novalek has continued with a scientific basis in its operations to the present day under the direction of Dr. Robert Rofen (Ph.D. biological-aquatic sciences). Novalek has been asked by concerned scientists to use its expertise to investigate the effect of selenium on brine shrimp naturally occurring in San Joaquin Valley evaporation pond systems.

The brine shrimp *Artemia franciscana franciscana* present in the evaporation ponds of the San Joaquin Valley are native to western North America, including California. Their eggs survive for years under dry conditions, being widely dispersed in the feathers of birds and by wind. They normally grow where there are hypersaline conditions that are lethal to their predators (fishes, crabs, larger crustaceans, etc.). They naturally occur in San Joaquin Valley evaporation ponds that have high alkalinity and are hypersaline. Brine shrimp are now well established with populations of many tons per pond, surviving as adults year round, even at their lowest population levels in winter. Selenium (Se) concentrations in brine shrimp from the evaporation ponds were found to be 0.5-1.2 ppm wet weight. These levels are substantially below levels harmful as a food source to aquaculture and aquarium animals.

Brine shrimp feed in the evaporation ponds on naturally occurring populations of phytoplankton and gram positive bacteria. The brine shrimp are reproducing normally in the evaporation ponds, both by bearing live young and encysted embryos ("eggs" = cysts). Brine shrimp live six months or more. With regular commercial harvesting from the evaporation ponds by Novalek, the life spans will be generally shortened, thereby diminishing the time that the brine shrimp accumulate selenium from the food chain and lowering retained selenium levels in their tissue. Growth rates of brine shrimp within the evaporation ponds are expected to increase due to lower population densities in the ponds.

Novalek is developing a long-term program for commercial harvesting of brine shrimp and daphnia from TLDD and other evaporation basins within the San Joaquin Valley. The harvested products are for the premium quality frozen and live product markets in the United States and Europe, mostly in Western Europe.

Summary

Research investigations are continuing to expand within the Tulare/Kern subarea to investigate methods for drainage water re-use. The primary focus of these investigations is on the application of agricultural drainage water for irrigation of salt-tolerant crops. Additional investigations include such activities as the use of drainage water for aquaculture production and the commercial harvest of brine shrimp. Research investigations into drainage water re-use in recent years have been promising. Funding has been committed to continuing these investigations.

Figure VE-1. Sketch of stratification in Rainbow Ranch Ponds (DWR, 1998)

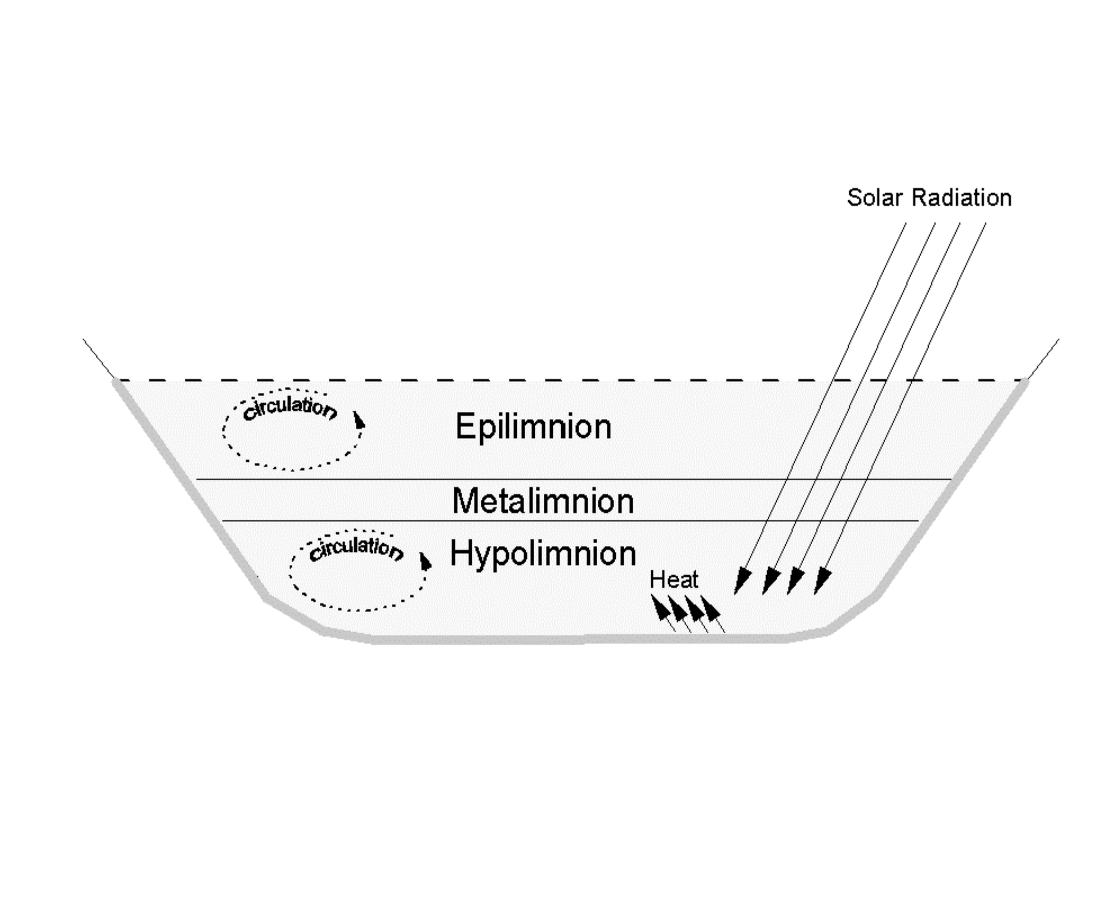


Figure VE-3. Stratification of temperature in a Rainbow Ranch Pond (DWR, 1998)

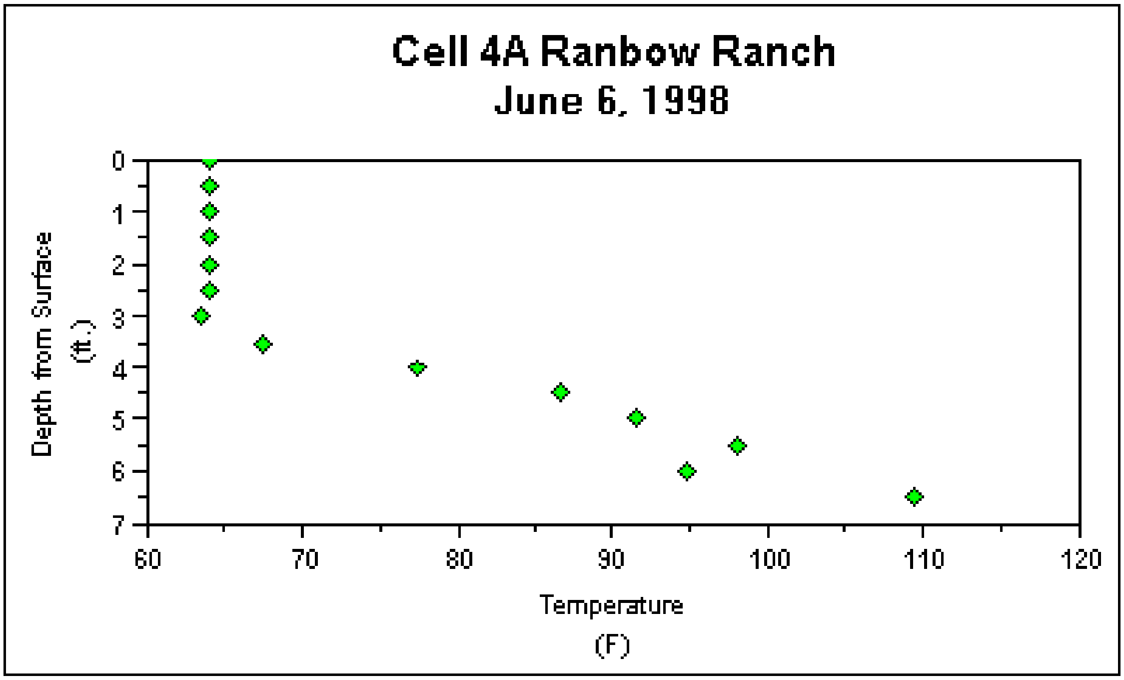
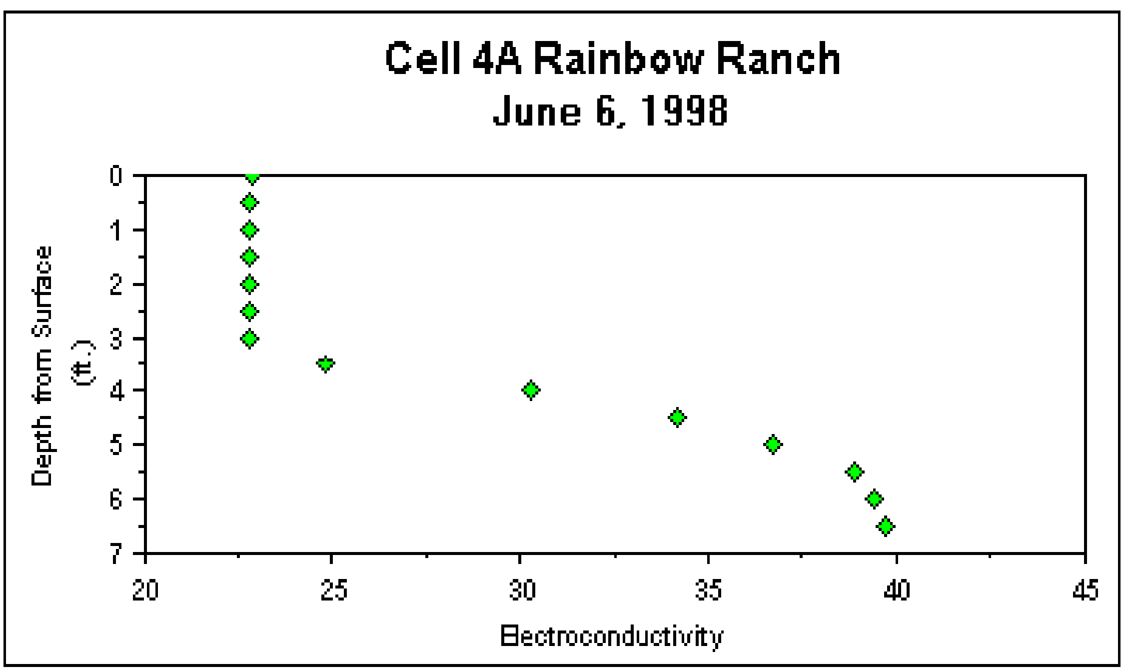


Figure VE-2- Stratification of salinity that may inhibit traverse of aquatic organisms in a Rainbow Ranch Pond (DWR, 1998), EC ,1000 µsimens/cm (mmohs/cm).



VI. Burning Questions

This Technical Committee generated a list of 11 burning questions in its first formal meeting. As noted below, it is somewhat disconcerting that we have difficulties in responding to these questions.

(1). Can evaporation basins be eliminated in irrigated lands with no surface discharge outlets?

The short answer is no in drainage impacted lands (Sections IA and 1D, and Fig. IA-2). Although a combination of management options are available such as reduction in subsurface drainage through improved irrigation and drainage systems and drainwater reuse, residual drainwaters will be produced and will need to be managed.

(2). Do evaporation ponds affect total bird population in the valley (net decrease or net increase or minimal)?

We do not have adequate data to respond to this question because quantitative data on waterbirds during pre-European settlement is not available) and pre-1985 bird counts are not available for the entire region where evaporation basins exist. Moreover, evaluating the role of evaporation ponds in the production and maintenance of current bird populations is difficult, due in part to lack of data. Annual variations in precipitation and flood management cause large annual variations in available wetland habitat and the proportion of habitat supplied by evaporation ponds. This issue is further complicated by consideration of wintering and migrating bird populations as well as breeding populations, and the mobility of the bird species in response to changing environmental conditions.

(3). What drainage water characteristics make evaporation ponds bird safe (are all ponds potentially toxic)?

No, not all ponds are potentially toxic. Selenium appears to be the principal toxic agent to waterbirds (Sections II and VD). The sole use of water-borne selenium concentration, neglecting sediment selenium, is now being questioned (Section VB). Encrusted dissolved mineral salts on wings may impair flight of birds.

(4). How can evaporation basins be managed to minimize (reduce) bird damage?

A number of mitigation measures adopted by pond operators since 1990 contribute to reducing bird damage (Section IVA). The on-site measures include minimum water depth of 2 feet, levee slopes as steep as practical, vegetation control, no exposed windbreaks, hazing, removal of tires on levee banks, invertebrate sampling, and disease control. In addition, alternative and compensation habitats are providing off-site mitigation (Section VD).

(5). Can alternative and compensation habitats mitigate damages from ponds and can they be quantified?

There is a growing data base supporting the benefits of alternative and compensation habitats. Additional data is desired to more conclusively demonstrate over a longer time span the utility of alternative and compensation habitat.

(6). Do we know the relationship between pond Se concentration and bird toxicity with sufficient certainty?

There appears to be adequate data to indicate such a relationship exists for black-necked stilt and American avocet but not others. The compensation habitat protocols utilize a number of criteria for risk assessment and only mitigate for impacts of evaporation basins on avian reproduction. Other impacts, if applicable, remain un-mitigated.

(7). When ponds are deactivated, what are the appropriate closure procedures?

The CVRWQCB requires certain procedures for pond closure (Section IVB). The long-term effectiveness of these closure requirements should be monitored.

(8). Are there any new promising technologies/studies that should be investigated?

Section V of this report contains major ongoing activities including the flow-through wetlands, algal bioremediation, solar evaporators, solar ponds and harvesting brine shrimps In addition, the Tulare/Kern Subarea Report identifies a number of other ongoing or potential studies to remove selenium and other constituents of concern from drainage waters (Report on Drainwater Treatment). The principle constraint is finding a process that reduces selenium to 2 ppb or less at economical costs. More than one treatment process may need to be coupled to reduce Se to desired levels and increase TDS to deposit salts or reduce TDS for reuse.

(9). Are the holding ponds and re-circulation basins present in the Westlands and Grassland subareas that look like evaporation ponds, but not operated as such, of concern?

This may be of concern to some but such practice has not been investigated for potential adverse impacts to birds.

(10). Is the 1990 recommended mitigation ratio of one acre of compensation habitat for one acre of contaminated (>2 ppb Se) of pond surface appropriate?

The short answer is no. Findings to present indicate it is less than a 1:1 ratio (Section VD). There are limits to the applicability of these findings, notably the small suite of species evaluated, lack of data on wintering and migrating birds, and the potential effects of variation in area and location of available wetlands other than evaporation basins.

(11). What are the costs of design, construction and operation of evaporation ponds and alternative habitats?

This question and other economic aspects will be addressed by the Ad Hoc Committee.

VIII. Research Needs

The interaction of physical, chemical and biological processes and conditions operating in evaporation basins is extremely complex. Since the early 1980s, we have gained substantial knowledge base in regard to the potential adverse conditions of evaporation basins and how to mitigate them. However, as noted in the previous section, we do not have sufficient information and data base to completely respond to the burning and other questions.

A compilation of research needs, not in any order of priority, are given below:

(1). Expand the species-specific research on American Avocet and black-necked stilt to other waterbirds.

(2). Further investigate the post-hatch juvenile mortality and sub-lethal and short-term Se exposure effects on birds.

(3). Based on the results of ongoing investigations on technology and practices, formulate a combination of management options for pond operators to further reduce potentially adverse impacts to birds and other wildlife.

(4). Quantify the net environmental benefits of alternative and compensation habitats.

(5). Monitor the effectiveness of pond closure measures on a long term basis.

(6). Determine if protein Se in the food chain is more toxic than other forms of Se.

(7). Ascertain more definitively, whether other constituents of concern such as boron, molybdenum, arsenic and uranium have deleterious effects on birds singly or in combination.

(8). Address the question of what criteria should be used for Se remediation.

(9). Investigate effects of selenium from evaporation ponds on taxa other than waterbirds.

(10). Investigate the role of the Tulare basin in the population biology of affected bird species over a larger region, such as the Central Valley, or Western Flyway.

(11). Investigate the potential effects of selenium and other evaporation pond constituents on wintering and migrating waterbirds.

IX. References Cited

Adams, W.J., Brix, K.V., Fairbrother, A., and Cardwell, R. 1997. Understanding selenium in the aquatic environment: A Learned Discourse. SETAC News 17: 22-23.

Amrhein, C., M.C. Duff, W.H. Casey, and D.W. Westcot. 1997. Emerging problems with uranium, vanadium, molybdenum, chromium, and boron. Pages 329-56, In: Agroecosystems: Sources, Control, and Remediation of Oxyanions, L.M. Dudley and J.C. Guitjens, editors, Proceedings of the Pacific Division, American Association for the Advancement of Science. San Francisco, CA. June 22, 1994.

Amrhein, C., P. A. Mosher, and A. D. Brown. 1993. The effects of redox on Mo, U, B, V, and As solubility in evaporation pond soils. Soil Sci. 155:249-255.

Belitz, K. 1988. Character and evolution of the ground-water flow system in the central part of the Western San Joaquin Valley, California. Open File Report 87-573, USGS.

Benson, S., Oswald, W.J., and Leighton, T. (1997). Demonstration of the Algal-Bacterial Selenium Removal Technology for Irrigation Drainage Water Treatment. Handout from and presentation at the 1997 Salinity/Drainage Annual Meeting, Sacramento, CA.

Benson, S., Oswald, W.J., and Leighton, T. 1997. Demonstration of the Algal-Bacterial Selenium Removal Technology for Irrigation Drainage Water Treatment. Handout from and presentation at the 1997 Salinity/Drainage Annual Meeting, Sacramento, CA.

Besser, J.M., Canfield, T.J., and La Point, T.W. 1993. Bioaccumulation of organic and inorganic selenium in a laboratory food chain. Environ. Toxicol. Chem. 12, 57-72.

Bradford, G.R., D. Bakhtar, and D.W. Westcot. 1990. Uranium, vanadium, and molybdenum in saline waters of California. J. Environ. Qual. 19:105-108.

Canton, S.P. and Van Derveer, W.D. 1997. Selenium toxicity to aquatic life: An argument for sediment-based water quality criteria. Environ. Toxicol. Chem. 16: 1255-1259.

Cherr, G. N. and Higashi, R.M. 1997. Toxicity Identification Evaluations are inherently research projects: A Learned Discourse. SETAC News 17: 19-20.

Chilcott, J.E., D.W. Westcot, A.L. Toto, and C.A. Enos. 1990. Water quality in evaporation basins used for the disposal of agricultural subsurface drainage water in the San Joaquin Valley, California, 1988 and 1989. California Regional Water Quality Control Board Central Valley Region, Sacramento, CA.

Croft, M.G. 1972. Subsurface Geology of the late tertiary and quaternary water-bearing deposits of the southern part of the San Joaquin Valley. Geological Survey Water-Supply Paper 1999-H, USGS, 29 pages.

Davis, D., P. Nixon, J. Hansen, and 15 others. 1998. Tulare/Kern Subarea Report. San Joaquin Valley Drainage Program, 65 pages.

Department of Water Resources. 1997. Tulare Basin Resources Assessment-Preliminary Report. Memorandum Report. September 1997, 58 pages.

DuBowy, P. 1989. Effects of diet on selenium bioaccumulation in marsh birds. *J. Wildlife Management* 53:776-781.

Fan, T.W.-M. and Higashi, R.M. 1998 Biochemical fate of selenium in microphytes: Natural bioremediation by volatilization and sedimentation in aquatic environments. Pages 545 – 563,_ In *Environmental Chemistry of Selenium*, W.T. Frankenberger, Jr., and R.A. Engberg, eds., Marcel Dekker, Inc., New York.

Fan, T.W.-M., A.N. Lane, and R.M. Higashi. 1997. Selenium biotransformations by a euryhaline mciroalga isolated from a saline evaporation pond. Environ. Sci. Technol. 31:569-576.

Ford, S. 1988. Agricultural drainage evaporation ponds in the San Joaquin Valley-Progress of Investigation. Memorandum Report. Department of Water Resources, xx pages.

Frankenberger, W.T. and Thompson-Eagle, E.T. 1989. *In Situ* volatilization of selenium. II. Evaporation ponds. Final Report to the San Joaquin Valley Drainage Program, U.S. Bureau of Reclamation Contract # 7-FC-20-05110, pp. 1-28.

H.T. Harvey & Associates, 1997. Rainbow Ranch Mitigation Assessment and Technical Report

Hamilton, S.J. 1997. Evaluation of contaminant impacts on razorback sucker in restored floodplain habitats and remediation techniques. Presentation at the Symposium "Understanding Selenium in the Aquatic Environment", Salt Lake City, UT, March 1997.

Hamilton, S.J., Buhl, K.J., Bullard, F.A., and McDonald, S.F. 1997. On-site toxicity test with razorback suckers at Ouray NWR, Utah. Presentation at the Symposium "Understanding Selenium in the Aquatic Environment", Salt Lake City, UT, March 1997.

Hanna, Jr., G. P., J. A. Kipps, L. P. Owens. 1990. Agricultural drainage treatment technology review. Memorandum Report to the San Joaquin Valley Drainage Program. Sacramento, CA. Under the U.S. Bureau of Reclamation Order No. 0-PG-20-01500.

Hansen, D., P.J. Duda, A. Zayed, and N. Terry. 1998. Selenium removal by constructed wetlands: Role of biological volatilization. Environmental Science & Technology 32(5): 591-597.

Hansen, H.C.B., C. B. Koch, H. Nancke-Krogh, O. K. Borggaard, and J. Sorensen. 1996. Abiotic nitrate reduction to ammonium: key role of green rust. Environ. Sci. Technol. 30:2053-2056.

Lemly, A.D. 1993. Teratogenic effects of selenium in natural populations of freshwater fish. Ecotoxicol. Environ. Saf. 26, 181-204.

Letey, J., C. Roberts, M. Penberth and C. Vasek. 1986. An agricultural dilemma: drainage water and toxics disposal in the San Joaquin Valley. University of California Kearney Foundation of Soil Science.

Lundquist, T.J., Green, F.B., Tresan, R.B., Newman, R.D., Oswald, W.J., and Gerhardt, M.B. 1994. The algal-bacterial selenium removal system: mechanisms and field study. Pages 251-278, IN: Selenium in the Environment, ed. W.T. Frankenberger, Jr. and S. Benson, Marcel Dekker Inc., New York.

Maier, K.J. and Knight, A.W. 1992. Selenium in Central Valley Evaporation Pond Systems. Final Technical Report to California Department of Water Resources, contracts #B-57232 and #B-57232-1. Land, Air and Water Resources Paper No. 100020, University of California, Davis, pp. 73-81.

Maier, K. J. and A. W. Knight. 1994. Ecotoxicology of selenium in freshwater systems. *Review of Environmental Contaminants and Toxicology.* 134:31-48

Maier, K.J. and Knight, A.W. 1994. Ecotoxicology of selenium in freshwater systems. *Rev. Environ. Contam. Toxicol*. 134, 31-48.

Moore, S.B., J. Winckel, S.J. Detwiler, S.A. Klasing, P.A. Gaul, N.R. Kanim, B.E. Kesser, A.B. DeBevec, K. Beardsley, and L.K. Plunkett. 1990. Fish and wildlife resources and agricultural drainage in the San Joaquin Valley, California. (Two Volumes) San Joaquin Valley Drainage Program, Sacramento, CA.

Myneni, S.C.B., T. K. Tokunaga, G. E. Brown, Jr. 1997. Abiotic selenium redox transformations in the presence of Fe(II,III) oxides. Science 278:1106-1109.

Nelson, D.C., Casey, W.H., Sisson, J.D., Mack, E.E., Ahmad, A., and Pollack, J.S. 1996. Selenium uptake by sulfur-accumulating bacteria. Geochim. Cosmochim. Acta 60: 3531-3539.

Northwest Economics Associates. 1997. Economic capacity of agriculture in Southern Kings and Northern Kern Counties. Vancouver, WA.

Ohlendorf, H. 1997. Toxicological effects of selenium on birds. Presentation at the Symposium "Understanding Selenium in the Aquatic Environment", Salt Lake City, UT, March 1997.

Ohlendorf, H. M. 1989. Bioaccumulation and effects of elevated selenium in wildlife. In L. W. Jacobs (eds.) *Selenium in Agriculture and the Environment*, pp. 133-177. American Society of Agronomy and Soil Science Society of America, Madison, WI

Ohlendorf, H. M., J.P. Skorupa, M. K. Saiki, and D. A. Barnum. 1993. Food-chain transfer of trace elements to wildlife. In R. G. Allen and C. M. U. Neale (eds.), *Management of Irrigation and Drainage Systems: Integrated Perspectives.* Pp. 596-603. American Society of Civil Engineers, New York.

Packer, L. and Knight, A. 1986. Utilization of blue-green algal (cyanobacteria) to Cleanse and Remove Se as an Option to Deal with Problems of Salinity and Drainage in the West Side of the San Joaquin Valley. Summarized in U.C. Salinity/Drainage Task Force Principal Accomplishments 1985-1990, Division of Agriculture and Natural Resources, University of California, 1991, p.37.

Parker, D.R., Amrhein, C., and Thompson, A. 1997. Fate and partitioning of selenium in a constructed wetland microcosm. IN: UC Salinity/Drainage Program Annual Report 1996-97, Division of Agriculture and Natural Resources, University of California, pp.156-163.

Parker, D.R., Amrhein, C., and Thompson, A. 1998. Fate and partitioning of selenium in a constructed wetland microcosm. IN: UC Salinity/Drainage Program Annual Report 1997-98, Division of Agriculture and Natural Resources, University of California, pp.159-167.

Reidel, G., Sanders, J., Gilmour, C., Goulden, C., Sanders, R., Breitburg, D., and Osman, R. 1997. Selenium interactions in aquatic ecosystems and effects on fish populations. Presentation at the Symposium "Understanding Selenium in the Aquatic Environment", Salt Lake City, UT, March 1997.

Salmon, T.P. and R. E. Marsh 1991. Effectiveness and Cost of Minimizing Bird Use on Agricultural Evaporation Ponds. CDWR Contract #B-57211. 118 pp.

San Joaquin Valley Drainage Program. 1990. A Management Plan for Agricultural Subsurface Drainage and Related Problems of the Westside San Joaquin Valley. A Final Report by the San Joaquin Valley Drainage Program. U.S. Department of Interior and California Resources Agency, Sacramento, CA, 183 pages.

San Joaquin Valley Interagency Drainage Program. 1979. Agricultural drainage and salt management in the San Joaquin Valley, final report including recommended plan and first-stage environmental impact report. U.S. Bureau of Reclamation, California Department of Water Resources, California Water Resources Control Board.

San Joaquin Valley Drainage Implementation Program. 1998. A status report on drainage management in the San Joaquin Valley, Division of Planning and Local Assistance, Department of water Resources, 65 pages.

Skorupa, J.P. 1998a. Selenium poisoning of fish and wildlife in nature: Lessons learned from twelve real-world examples. Chapter 18, pp 315-353, IN Environmental Chemistry of Selenium, W.T. Frankenburger, Jr., and R. A. Engberg, Editors, Marcel Dekker, Inc.

Skorupa, J.P. 1998b. Risk assessment for the biota database of the National Irrigation Water Quality Program (NIWQP). Rept. To NIWQP, USF&WS, Sacramento, CA

Skorupa, J.P.; and Ohlendorf, H.M. 1991. Contaminants in drainage water and avian risk thresholds. In: *The Economy and Management of Water and Drainage in Agriculture*; Dinar, A. and Zilberman, D., Eds, Kluwer Academic Publishers: Norwell, MA, p. 345-368.

Tanji, K.K. 1989. Chemistry of toxic elements (As, B, Mo, Se) accumulating in agricultural evaporation ponds. Pages 109-121. In J.B. Summers & S. S. Anderson, eds., *Toxic Substances in Agricultural Water Supply and Drainage.* Symposium proceedings from the Second Pan-American Regional Conference of the International Commission on Irrigation and Drainage. Ottawa, Canada. June 8-9, 1989. U.S. Committee on Irrigation and Drainage, Denver, CO.

Tanji, K., S. Ford, A. Toto, J. Summers, and L. Willardson. 1993. Evaporation ponds: What are they; why some concerns. Pages 573-579, IN Proceedings, Management of Irrigation and Drainage Systems: Integrated Perspectives, ASCE National Irrigation and Drainage Engineering Conference, R.G. Allen and C.M.U. Neale, editors, Park City, UT, July 21-23, 1993.

Tanji, K.K., S. Gao, D. Peters, and A. Quek. 1997. Application of TEAPS for the evaluation of selenium redox chemistry in the TLDD wetland system. IN: UC Salinity/Drainage Program Annual Report 1996-97, Division of Agriculture and Natural Resources, University of California, pp.233-237.

Tanji, K., D. Peters, and S. Gao. 1998. TLDD flow-through wetland system for the removal of selenium in irrigation drainage waters before discharge into evaporation ponds. Progress Report to CA Dept. of Water Resources, March to September 1998, 21 pages.

Tanji, K., S. Gao, D. Peters, and A. Quek. 1999. Application of TEAPS for the evaluation of selenium redox chemistry in the TLDD wetland system. Annual Progress Report to UC Salinity Program, 13 pages (in press).

Terry, N. 1997. Use of flow-through constructed wetlands for the remediation of selenium in agricultural tiled-drainage water. UC Salinity/Drainage Program Annual Report for 1996-1997. Pp. 106-123. Centers for Water & Wildland Resources.

Terry, N. 1998. Use of flow-through constructed wetlands for the remediation of selenium in agricultural tiled-drainage water. UC Salinity/Drainage Program Annual Report for 1997-1998. Pp. 56-112. Centers for Water & Wildland Resources

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